3TU.

ICT at 3TU
NIRICT Research Plan 2007

TU Delft
Technische Universiteit Delft

TU/e technische universiteit eindhoven

Universiteit Twente
de ondernemende universiteit

3TU.

NIRICT
Netherlands Institute for Research on ICT

ICT at 3TU
NIRICT Research Plan 2007

3TU.

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'To be an internationally leading scientific research institute and partner in innovation for the technology of advanced information and communication systems'

To stay competitive on a global scale, and to create excellence in research, the three Universities of Technology in the Netherlands have decided to join forces, and to create mass and focus around a number of strong poles of expertise.

Next to excellence in research, society and industry increasingly expect an active role of the technical universities (TU's) in innovation. Consortia consisting of industry and academia are formed to address societal and industrial problems. Examples are the European Technology Platforms, the High-Tech Campus in Eindhoven, Point-One, the ICT Innovation Platforms (IIP) of ICTRegie, etc. In addition, research funding is more and more organized in a thematic way, as exemplified by the Framework Programs of the EU, the BSIK programs, and the NWO thematic programs.

To participate in these consortia it is necessary for the relevant research communities to show sufficient critical mass on these themes, and to be organized on sufficiently large scale. Further, to be able to contribute to research and innovation agendas, university groups should be involved in the phase when the research agendas are defined.

The set up of NIRICT is based on these ideas. NIRICT, which stands for Netherlands Institute for Research on ICT, bundles the ICT research of the 3TU's, and aims at setting a number of strategic research agendas by combining expertise from the 3TU's in a coherent fashion, and creating focus and mass through the combination of strong poles of expertise. By being a partner in discussions on research agendas and in consortia, NIRICT provides on the one hand access to research and innovation funding for its participating chairs, and contributes on the other hand to the innovation process by being a partner both at the national and European level.

3TU.

Contents

1. Introduction

Aim of NIRICT is to bundle the ICT research of the 3 TU's and to strengthen the cooperation in order to create sufficient critical mass around a number of research topics and have impact by focusing on a limited number of ICT topics and ICT applications.

3TU ICT Centre of Competence

In 2005 the three Dutch Universities of Technology (Delft, Eindhoven and Twente) agreed to work towards a confederation that would bring together their expertise within one organisation to strengthen its research, education, and innovation. A first step towards a confederation was to organize expertise areas in "Centres of Competence". The CoC NIRICT which stands for Netherlands Institute for Research on ICT, was one of the first CoC's due to the dominant position of ICT research within these three universities. Within each CoC one or more 3TU.Centres may be established. Within NIRICT the first 3TU.Centre is called CeDICT, which stands for "Centre for Dependable ICT systems (CeDICT)".

NIRICT is a virtual institute that encompasses 79 groups at the three universities and covers a broad spectrum of ICT research. The participating groups mainly originate in computer science, electrical engineering, mathematics and physics; however, also some application areas are involved. Bringing together ICT and applications is regarded as important. Both worlds can benefit from it, both from a scientific and an innovation point of view. The research volume paid by the universities is 40 M€ (permanent staff and infrastructure); the total turnover is more than 75 M€. The total man power is close to 840 fte's, of which app 270 fte's (mainly the tenured senior staff) are financed by the universities themselves. In total 1200 persons are participating. Founding an ICT institute of this size is unique in the Netherlands and its existence will increase the international visibility of Dutch ICT research.
In Appendix 1 an overview is given of the participating chairs.

Aim and mission
By founding NIRICT the following goals are pursued:

- to create sufficient critical mass around a limited number of research topics
- to have impact by focusing on a limited number of ICT topics and ICT applications
- to strengthen the cooperation and to make agreements on core activities among the three universities
- to play a leading role in the definition of the Dutch ICT research and innovation agendas and to increase Dutch influence on the EU ICT research agenda
- to prepare for EU programs (FP7, …) in a number of strategic areas
- to be preferred partner in ICT research and innovation
- to integrate the knowledge gained in the ICT educational programs.

NIRICT (Netherlands Institute for Research on ICT)

Partners

TUD
Delft Research Centre ICT, with participating groups from the Faculty of Electrical Engineering, Mathematics and Computer Science, Faculty of Technology, Policy and Management, Faculty of Industrial Design Engineering

TU/e
Groups from the Faculty of Electrical Engineering, Faculty of Mathematics and Computer Science, Faculty of Industrial Design, Faculty of Technology Management

UT
Center for Telematics and Information Technology (CTIT) with participating groups from the Faculty of Electrical Engineering, Mathematics and Computer Science, Faculty of Engineering Technology School of Management and Governance, Faculty of Behavioral Sciences.

Relationship with other organizations
Chairs participate in the following research schools: ASCI, Beta, Cobra, Dimes, IPA, and SIKS. At the national level the 3TU institutes are cooperating with the Telematics Institute and the Embedded Systems Institute.

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prof.dr. ir. H. Corporaal (TUE)
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Because of the enabling character of ICT, there is both a large variety of potential application domains and a whole range of ICT research disciplines. The Innovation Platform considers ICT as an innovation-axis, since it enables market and process innovation in many key domains of the Dutch economy. NIRICT has a strong bond with the "sleutelgebieden" High-Tech Systems and Materials, and Creative Industries. NIRICT aims at contributing to this research and innovation agenda and to address also other areas that are of societal or economical relevance, such as health, mobility, safety, and logistics.

Within FP7, research is organized around 4 programs: Cooperation, Ideas, People, and Capacities. Cooperation focuses on large transnational cooperation projects and is of high interest to NIRICT. Of the 9 themes within Cooperation, Information and Communication Technologies is the most relevant for NIRICT. Within Information and Communication Technologies four activities are distinguished: (1) ICT Technology Pillars, (2) Integration of Technologies, (3) Applications Research, and (4) Future and Emerging Technologies. All ICT Technology Pillars and almost all Integration of Technologies have substantial overlap with the NIRICT themes. The activity Applications Research has substantial overlap with the NIRICT Innovation Agenda. Relevant platforms are: ENIAC, ARTEMIS, e-Mobility, NEM, Manufacture, ERTAC.

Finally, NIRICT wants to make a strong effort in fostering innovation. Entrepreneurship and the creation of new jobs require a knowledge-rich environment. Concentration of knowledge can take place within a physical environment ('valley' or 'science park') or within a virtual heterogeneous network organization of large companies, SME's and knowledge institutes (or a combination of both). NIRICT wants to promote knowledge transfer through its Innovation Agenda and Research Labs (see below).

Research Agenda

To address the above challenges, NIRICT has three types of research agendas:

- Long Term Challenges
- Strategic Research Agenda
- Innovation Agenda

Long Term Challenges

The NIRICT Long Term Challenges (LTC) are a selection of a few research topics that can be characterized by high complexity, high risk/high return, and high relevance and a horizon of at least 8 years. The aim is to bring top research from the three partners together on a new and exiting theme.

The first LTC (and first 3TU.Centre within NIRICT) is "Centre for Dependable ICT systems (CeDICT)". More and more applications depend on the reliability, availability, integrity, and maintainability of ICT systems. Due to the increase of complexity at the hardware, software, and communication level, creating dependable systems has become a major scientific and engineering challenge. This topic is discussed in more detail in Section 2.

Strategic Research Agenda

NIRICT will focus its main research activity on a limited number of ICT topics with a horizon of 5-8 years. The choices made for the SRA themes are based on the current expertise and highly inspired by the NOAG-ICT (national research agenda on ICT) and the Strategic Plan of ICTRegie. This has led to the following themes:

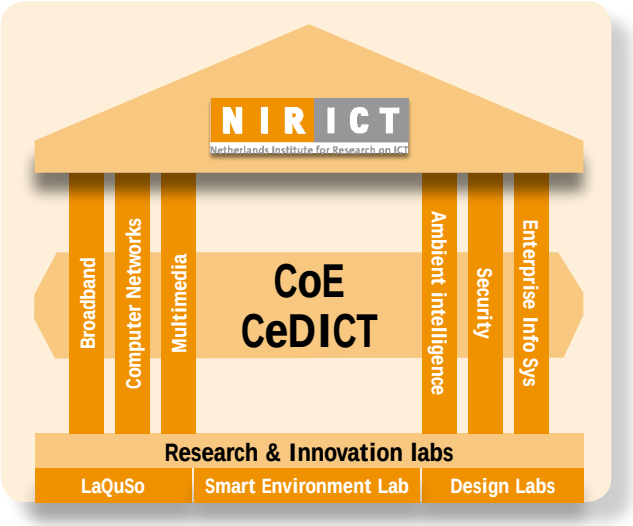
- Broadband Communication Systems: research within this theme is related to technology for optical-electrical broadband connections, and antenna technology and spectrum management for wireless communication
- Computer Networks: research on network technology that will provide seamless access to the underlying broadband infrastructure and high level communication services to the user.
- Ambient Intelligence: research on distributed sensor networks that will provide intelligence in products and in living and working environments.
- Security: research on mechanisms to make computer systems and the internet more secure and trustworthy.
- Multimedia and Interaction: research on natural interaction with intelligent systems and research

on search and presentation techniques for multimedia data.
- Enterprise Information Systems: research on design methodologies for next generation information systems, in particular architectural modeling for intra-organizational business processes.

These topics are discussed in more detail in Section 3.

Within these technology-oriented themes NIRICT will focus on a limited number of applications with societal and economic relevance. NIRICT will take the lead in:
- ICT for Healthcare: technology and infrastructures to enable personal health monitoring and to streamline information processing in the health sector
- ICT for Safety: technology for monitoring, interpretation and decision making in accidents and other emergency cases, and to provide adhoc communication networks to support emergency services (police, fire brigade, ambulances, etc).
- ICT for Mobility: technology for road management, safety guidance, road pricing and context-aware services.
- ICT for Logistics: systems for routing and planning and algorithms for scheduling
- ICT at home: multimedia interfaces for personal and social computing related to daily tasks such as learning, shopping, entertainment, teleconferencing, communities, etc.

In other application areas NIRICT will join initiatives lead by research parties in ICT. Within these themes public-private projects will start. See section 4.



Innovation Agenda
NIRICT will build upon the existing knowledge transfer and spin-off activities of the 3TU's. Groups within NIRICT already participate in many national and international projects based on consortia consisting of industry and academia. Think of the many projects in FP6 and Bsik, besides many bilateral contracts.

To strengthen the knowledge transfer within the themes of the SRA the **NIRICT Research Lab** (NRL) is founded. The NRL was started to put more emphasis on integrated tool and prototype development for various aspects of requirements, analysis, and design to obtain tool boxes. These tool boxes and prototypes will make the research results more concrete and will stimulate the interaction with both larger companies and SMEs.

The NRL consists of:
- LaQuSo(Laboratory for Quality Software): this lab will be "the" expertise and research centre for verification and validation of software systems. LaQuSo will bridge the gap between scientific computer science and software industry. It will make tools and techniques available for measuring, quantifying and predicting the quality of software.
- Design Labs: aim is to provide a design platform to allow also small companies to make a design for heterogeneous systems which may contain different components such as sensors, intelligent signal processing components and a low power radio. The design platform will contain a repository of information, past designs and tools that should allow each designer to have easy

access to all the knowledge and practical experience he or she needs to design such systems.

- Smart Environments Lab (SEL): techniques for ambient intelligence and multi-modal interaction can only be assessed in a realistic environment. This lab will be the place where the home of the future can be simulated and experienced. It offers people the opportunity to participate in new applications and validation tests. The lab will offer researchers the opportunity to observe the use of technology under realistic conditions.

Knowledge transfer in specific areas takes place in cooperation with TI, ESI, and TNO-ICT. In Section 5 more detail is provided.

2. Long Term Challenges

The NIRICT Long Term Challenges are a selection of a few research topics that can be characterized by high complexity, high risk/high return, and high relevance and a horizon of at least 8 years. The first one is "3TU.Centre for Dependable ICT systems (CeDICT)".

Dependable systems

More and more applications depend on the reliability, availability, integrity, and maintainability of ICT systems. Due to the increase of complexity at the hardware, software, and communication level, creating dependable systems has become a major scientific and engineering challenge

ICT is everywhere and in each appliance. Think of embedded systems (fly-by-wire, drive-by-wire, logistics control, mobile communications) but also of e-business systems (online auctions, online-retail, bank and stock-exchange trading systems) and medical systems (e.g. cardio/vascular X-ray machines for interventional radiology). Good and reliable functioning of these systems is essential and the increasing societal and business reliance on correct and timely operation of ICT systems asks explicitly for a high level of "dependability". In the past, dependability was an explicit design issue only for mission-critical systems, like in aeronautics, aerospace and military applications. Nowadays, medical and business systems might not be as mission-critical as a space mission, but are still that critical that lifes are threatened and high costs are incurred in case of malfunctioning of ICT components. Despite long-standing efforts, the solutions proposed in classical mission-critical systems are not directly transferable to the much broader class of ICT systems today. For one, cost is a major issue. The classical approach to achieve dependable systems often involves very expensive specialized hard- and software, that cannot be applied in the more consumer-oriented markets of today.

Moreover, there are a number of reasons why systems tend to become more un-dependable.

- ICT systems include more and more software, and software is notoriously not error-free.
- The interaction of the software and the hardware and the fact that most current ICT systems these days are distributed systems, makes designing error-free systems an illusion.
- The ever decreasing feature size of the hardware components increases the chances for hardware induced errors (bit flips, cross-over).
- Where in traditional dependable systems communication is typically based on reliable wired links (often even duplicated), nowadays communication takes often place over error-prone wireless links.
- ICT systems are not only being used by specialists; in practice this means that faults can be caused by human operators or system users.

Centre for Dependable ICT Systems (CeDICT)

Scientific leaders
prof.dr.ir. Boudewijn Haverkort, prof.dr.ir. Wil van der Aalst, prof.dr. Arie van Deursen

Participating chairs of NIRICT

TUD
Prof.dr. Arie van Deursen, Software Engineering
Prof.dr. Inald Lagendijk, Information and Communication Theory
Prof.dr. Stamatis Vassiliadis, Computer Engineering
Prof.dr.ir. Alle-Jan van der Veen, Circuits and Systems

TU/e
Prof.dr.ir. Wil van der Aalst, Information Systems
Prof.dr. Henk Corporaal, Embedded System Architecture
Prof.dr. Jan-Friso Groote, Design and Analysis of Systems
Prof.ir. Ton Koonen, Broadband Communication Networks

UT
Prof.dr. Ed Brinksma, dr.ir. Arend Rensink, Formal Methods and Tools for Open Systems
Prof.dr.ir. Boudewijn Haverkort, Design and Analysis of Communication Systems
Prof.dr. Pieter Hartel, Distributed and Embedded Systems
Prof.dr.ir. Bram Nauta, Integrated Circuit Design

New chairs
Next to these existing chairs, new chairs are being hired on Dependable Ad Hoc Networking (TUD), Dependable Multimedia Processing (TUD), Short-Range Radio (UT), Formal Methods and Tools (UT), Embedded System Security (TU/e) and Network Communication Protocols (TU/e).

As a result of these reasons, dependability enhancing techniques will become more and more needed, already to maintain existing levels of acceptable system dependability, let alone, to increase system dependability.

Aim and mission
Given the above problems, the aim of CeDICT is to develop and apply methods and techniques to make dependable ICT systems (commercial consumer-market systems, as well as specialized systems) a reality. Depending on the specific application area and the effective constraints, one or more of several dependability-enhancing techniques ("dependability means") will be chosen. One of the explicit aims of CeDICT is to view dependability as a system-wide issue that has to be addressed as such, given a dependability budget, and, therefore, not to focus *a priori* on one particular dependability means.

The quality of the constructed dependable systems must be quantifiable, which is currently not possible at all. Furthermore, the quality of the systems as a whole, and this explicitly includes its software, should be guaranteed (fixed or probabilistically). System and software design methods must be developed that make sure the required quality is inherently guaranteed. In practice, this means that researchers with different background and expertise (hardware vs. software design, communication vs. computation, and so on) have to cooperate on solving system-wide dependability problems. This will also lead to new, cross-layer, dependability solutions.
In summary, the mission of CeDICT is to develop the methods, techniques and tools necessary to design and implement truly dependable ICT-systems under cost and resource constraints.

Academic partners
CeDICT cooperates with partners outside of its core structure, both from within 3TU and outside of it, depending on the project needs. As an example, for the recently submitted Smartmix proposal on "Dependable Embedded Systems" partners from within 3TU were added, as well as from Free University, Amsterdam. Next to that, co-operations with CWI (Amsterdam) and the ESI (Embedded Systems Institute, Eindhoven) are foreseen; In fact, ESI and CeDICT together took the lead in the above Smartmix proposal.

Industrial partners
CeDICT does not currently have fixed industrial partners, but expects to cooperate with leading industries in the Netherlands (like Philips Research, NXP Semiconductors, Thales Communications, ASML, Oce, IBM, Devlab) and throughout the rest of the world.

Application areas
The application areas that would benefit most from our research on dependability are found in the HiTech industry, where Philips, ASML and OCE are important players, together with hundreds of SME who provide services and products to the main players and to the market. This area is explicitly addressed in our recent Smartmix proposal.
Dependability is also a key concern in the services market (7x24 availability of online services); major retailers, banks and insurance companies are important players in this field. We envisage to develop projects with partners in this field as well.
A third important area of application concerns "critical infrastructures", more in particular, infrastructures that are "run" using ICT, such as the power grid or the international gas and oil grids. The dependability of the ICT support system in these fields is paramount to the economy of (western) societies. Here also the robustness against malicious failures (attacks) plays an important role. We envisage to develop projects in this field as well.

Economic relevance
ICT proliferates in all branches of society and supports many critical processes (business processes, but more and more technical processes in embedded systems). The smooth operation of all these processes is paramount for the growth of our economy. Stated differently, the non-operation of all these processes has a direct economical impact, and in some cases even can be life threatening.

Dissemination of results
Research results will be disseminated through the usual scientific channels, that is, international refereed conferences and journals. Ph.D. dissertations written in CeDICT projects will be made publicly available. During CeDICT projects in cooperation with industries, the CeDICT chairs will actively contribute to valorization of the research results.

3. Strategic Research Agenda

NIRICT will focus its main research activity on a limited number of ICT topics with a horizon of 5-8 years. The choices made for the SRA themes are highly based on the NOAG-ICT (national research agenda on ICT) and on the Strategic Plan of ICTRegie

Broadband Communication Systems

Broadband telecommunication means are of vital importance to run our modern society, which is becoming ever more dependent on information, at any time, anywhere. These means form the arteries and the veins for economic activities ranging from research to manufacturing, for transport, health care, banking, logistics, leisure activities, etc. They need to span the globe, but also have to reach out to the individual users. Broadband communication technologies are needed providing transparently ample communication capacity, both wireless and wired, at affordable costs for the end users, yielding a traffic-jam free communication world.

Aim and Mission

All network levels need to co-operate tightly in order to achieve flawless end-to-end communication. Our vision is a seamless ultra-broadband communication network, the "boundless communication ether", where connections between the hierarchical network layers are made fully transparent and end-to-end all-optical communication is established, with a possible exception for the last link to the user devices, which in the majority of cases will be by wireless radio signals (potentially also wireless optical signals). It encompasses all-optical traffic routing and interworking with wireless high-capacity last drop links to the end users, such that the user experiences a virtually congestion-free instantaneous access to any service demands he may have. The vision opens the route to the ultimate in flexibility and capacity of telecommunications, and augmented by means of seamless wireless (optical) connections to the user also to the ultimate in user mobility; thus the "anywhere-anytime-anything-anyhow" provisioning of broadband telecommunication services can be achieved.
The common goal in this SRA theme is to *provide the technological basis for such a wide-ranging self-organising (cognitive) network*, which possesses the transparency to provide a wide variety of communication signals and the intelligence to locate by itself the resources with the adequate capabilities requested by the user.
To provide the infrastructural means in order to reach this common goal, three research tracks are foreseen:

Wideband communication techniques

Techniques will be explored, which enable to exploit a wide frequency range in the radio spectrum, e.g. 0.5-10.6 GHz, or several GHz around an e.g. 60 GHz carrier. In particular, these techniques encompass wideband frontend stages for radio transceivers which should be low in power consumption for saving battery life. Such wideband signals also require carefully designed antennas, matching the signals' propagation characteristics. The system robustness can be further enhanced by antenna diversity schemes, multi-input multi-output signal processing algorithmes, and wideband scanning schemes. Also adaptive coding and signal modulation schemes will improve the wideband system performance characteristics.

Self-organised adaptive spectrum utilization techniques

As the heavy usage of radio spectrum necessitates a scrutinous and efficient deployment of spectrum resources, techniques need to be explored, which optimize

SRA "Broadband Communication Systems"

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TUD
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Prof.dr.ir. Kees Beenakker - Large-area electronics, Prof.dr.ir. Alle-Jan van der Veen – Circuits and Systems
Prof.dr.ir. Ignas Niemegeers - Wireless & Mobile Communications
Prof.dr. Lina Sarro – Electr. Comp. Techn. & Materials

TUE
Prof.dr. Anton Tijhuis – Electromagnetics, Prof.ir. Ton Koonen - Electro Optical Communication Systems
Prof.dr.ir. Erik Fledderus – Radiocommunication
Prof.dr.ir. Meint Smit - Opto-electronic Devices
Prof.dr.ir. Arthur van Roermund - Mixed Signal Microelectronics
Prof.dr.ir. Jan Bergmans - Signal Processing Systems
Dr. Richard Nötzel - Photonics
Prof.dr. René Janssen - Molecular Materials and Nanosystems
Prof.dr.mr. Jan Smits -Technology Management, Prof.dr.ir. Onn Boxma - Stochastic Operations Research
Prof.dr.ir. Henk van Tilborg -Discrete Mathematics

UT
Prof.dr. Alfred Driessen - Integrated Optical Micro Systems
Prof.dr. Bram Nauta - Integrated Circuit Design, Prof.dr.ir. Kees Slump - Signals and Systems
Prof.dr.ir. Boudewijn Haverkort, Prof.ir. Kees van Bochove - Design and Analysis of Comm. Systems
Prof.dr.ir. Wim van Etten - Telecommunication Engineering

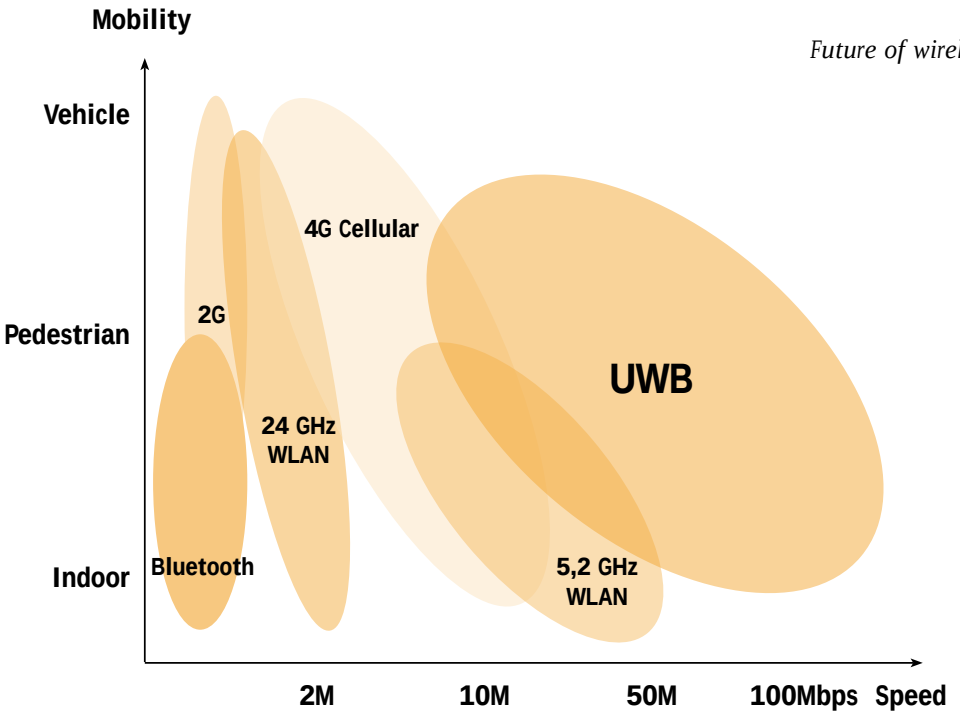
the usage of the available radio spectrum by meeting the capacity and Quality of Service demands of the user while at the same time minimizing the interference with radio channels serving other users. Such radio spectrum optimization techniques should be based on theoretical spectral efficiency benchmarks for spectrum re-use, and affiliated transmit power control schemes for ad-hoc spectrum re-use. They will deploy smart analog frontends for these functionalities, and antennas as well as digital baseband hardware and software for optimizing the radio channel characteristics. The overall system needs an efficient and operationally stable frequency allocation policy, allowing users to connect via fair shared access protocols, and giving them adequate Quality of Service and security.

Flexibly routed format-transparent signal transport
In order to interconnect smoothly and without congestion the users in their geographically spread wireless cells, techniques will be explored which provide the means for interconnecting these cells in a way which is transparent to the various signal formats used, thus extending the coverage of cognitive networking. These techniques will encompass wireless optics techniques providing line-of-sight high-capacity connections, as well as optical techniques for transporting (ultra-)wideband techniques via optical fibre. The interconnecting optical fibre backbone network will have optical ad-hoc reconfiguration functions, which can be set to deliver capacity and QoS on-demand at any location. At the edges, such a network needs wideband power-efficient converters translating radio signals into optical ones and vice-versa, while within the network optical multiplexing and routing functions are needed for transporting and delivering the radio signals to their appropriate destinations. These optical functions encompass wavelength-specific routing, wideband optical amplification, and fast optical signal processing for optical crossconnecting and add/drop/continue functions.

Cooperation with industry, operators, ...
Within these research tracks, close cooperations are foreseen between the industries and the university groups, encompassing joint experiments in laboratories, traineeships for knowledge transfer and hands-on exercises, on-the-job training for new employees and/or re-education for employees in job rotation.

The research is related to (semi) industrial interests:
- in the Netherlands: at Philips, TNO-ICT, TNO-FEL, Lucent Technologies, KPN, TI-WMC, Thales, Draka Comteq Fibre, Genexis, Lionix, Cedova, ASTRON, SurfNet, Baas, ...
- internationally: at Siemens, Fujitsu, Asahi Glass, KDDI, Lucent, Ericsson-Marconi, ...

Moreover, there will be international exposure, a.o. by the involvement of the university partners in many international and national projects (such as presently in e.g. the EC's 6th Framework Programme, the WWRF, several projects in the national programmes Freeband, IOP GenCom, ...).



Future of wireless technology

Abundant Networks & Services

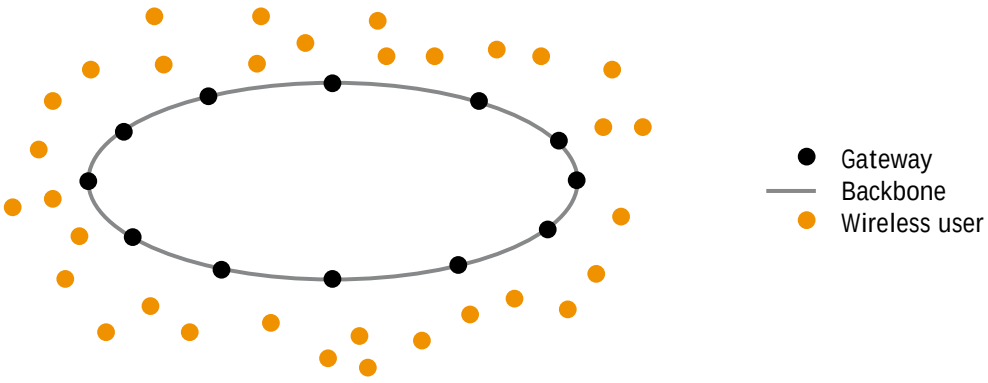
The SRA theme Computer Networks addresses the issue of how to offer anybody, anytime, anywhere, "liquid bandwidth", through a heterogeneous network of (local) wireless links and (global) broadband fiber networks. Key aspects are adaptively, dependability, interoperability, and maintainability

The abundant and increasing availability of wireless connectivity, (e.g., in consumer-installed wifi access points and operator-owned cellular networks), and the potential of using wireless multihop techniques, such as in mesh or ad-hoc networks, provides the potential for omnipresent, abundant network access for users, services and devices. For a specific user, service or device, it is highly likely that at a certain location and time, communication means will be available for him to communicate through a broadband connection with other users, and services and devices somewhere in the world.

Aim and Mission
The SRA theme Computer Networks addresses the issue of how to incorporate all these (wireless) links into a system providing "liquid bandwidth", anytime anywhere, like IP and web technology have done for computer networks. Prerequisites for such a system are the availability of ubiquitous computing, wireless communication, and broadband networks. The main challenge is how to bundle all communication and computation ("compunication") capabilities that are often "owned" by users themselves (e.g. wifi access points), into a cooperative, self-organizing, adaptive grid, where each user is both producer / provider and consumer / user of (communication / content) services. Such cooperative networking should ensure that abundantly available, uncoordinated, and unpredictable "compunication" facilities can support processes in our society.

Examples of applications are to further increase safety and efficiency in transport, e.g., by using car-to-car communication, to enhance personal comfort and safety by using personalized networks, to enhance organizational efficiency by using trans-sectoral networks and composable business support services, and to support processes in specific domains like healthcare for cure, care and wellbeing through continuous and unobtrusive health monitoring.

Future heterogeneous networks need to possess high degrees of autonomy and self configurability because classical operation and maintenance methods are hardly applicable to these network types. We envisage the heterogeneous network of the future to consist of some ad-hoc elements combined with infrastructure based network support. Communication over short distances and with users in the direct vicinity could be supported in ad-hoc mode, while long-distance communication would make use of the existing fixed infrastructure. In this network, peer-to-peer communication between any two nodes could be supported, generating an overlay network structure.



SRA Computer networks

Scientific leader
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TUD
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Prof.dr. Jens Arnbak, Networks, Architectures and Services
Prof.dr.ir. Nico Baken, Networks, Architectures and Services

TU/e
Prof.ir. Ton Koonen, Electro-Optical Communication Systems
Prof.dr.ir. Erik Fledderus, Radio Communication
Prof.dr.ir. OnnoBoxma, Stochastic Decision Making

UT
Prof.dr.ir. Boudewijn Haverkort, Design and Analysis of Communication Systems
Prof.dr. Pieter Hartel, Distributed & Embedded Systems
Prof.dr. Richard Boucherie, Stochastic and Operations Research

Academic partners
NIRICT, Telematica Instituut, TNO ICT, TNO Transport, Holst Centre, University of Amsterdam, University of Utrecht.

Cooperation / industry
TI-WMC, Lucent Bell Labs, Ericsson, Philips, Surfnet, KPN, Thales, 3UB.

Current and future mobile and wireless networks enable new services for end-users/consumers that should be user-centric (e.g. I-centric or We-centric). Working from the premise that users are connected virtually at any time and any place, new ways of interacting among users and between users and networked services become possible.

In the future new business models may prevail overcoming the traditional hierarchy of consumer, service provider and network provider. The traditional distinction between a user and provider will blur. Typically, the end-user that now predominantly consumes services will change into a provider of communication and networked services. Blogging is possibly an early example of an end-user provided information service. User-centric computing and networking may also lead to the extension of the peer-2-peer model for sharing content to a cross-cutting peer-2-peer model for sharing communication, computation and information resources. Applying a service-oriented approach to user-centric computing and networking is a promising way forward. Challenges that need further research include the mechanisms to publish services (i.e., service directories), service discovery (i.e. interworking between heterogeneous service discovery protocols) and service binding (i.e. session management and control in case of a disruptive networking environment).

Design of heterogeneous networks
To support the design of these heterogeneous computer networks *generic methods, techniques and tools* are needed to assess the performance, dependability and security (and possibly evolvability and maintainability) of these networks, i.e. performance expressed in terms of throughput, delay or loss measures, given a certain traffic mix, and dependability in terms of minimum availability over each year, or the maximum time between outages, and so on. To be able to analyze designs, the design itself has to be described in a formalized language, not only to proof functional correctness, but especially also to be able to verify whether performance and dependability characteristics are met. Using techniques known from *stochastic operations research* (queuing theory, stochastic processes, Markov chains, discrete-event simulation), these formalized designs should be analyzed to certify adequate performance and dependability. At the same time, preferably from the same formalized design, functional properties should be verified, using techniques like *model checking*. Next to that, *graph theoretical methods* are needed to assess topological issues, especially in large IP-based networks; such topological descriptions can be used to characterize traffic streams, hence, form important input to the stochastic models that are used to obtain performance characteristics. Next to model-based analysis methods to support the design, in later phases of the design process, when parts of the system are operational, *measurement techniques* will play a more important role. Such techniques require a detailed knowledge and insight in operational networking systems and their protocols, as well as in statistical techniques to capture the necessary information in a correct (unbiased) and non-intrusive way. Measurements also form the necessary input to *workload characterization methods*, in which measured workloads (traces) are used to parameterize easy-to-handle stochastic workload models.

Self-organization and self-management
A key aspect in future networking systems will be their ability to adapt at runtime, e.g., based on context-awareness or any other self-awareness (including self-reflection; cf. reflective systems). Aim of adaptation is to self-tune the system's functionality (services) and performance and/or dependability automatically and autonomously. When systems increase in size and complexity, this is the only viable approach to pursue, since one cannot anticipate all possible system and environmental configurations a priori. A promising technique in this respect is model-based adaptation, in which the adaptation process is governed by an underlying mathematical system model. Notice that in this approach, the adaptation process in fact comprises a very general class of closed-loop control systems; adequate control theory for this type of systems is currently not well developed. Although many different technology-based solutions exist for adaptive systems, an overall architecture in which the different technologies can be positioned and related to each other, is still not available.

Given that we expect every artifact to be equipped with computing and communication capabilities, we have to face a large heterogeneity of device capabilities and energy supply. Already now we see systems consisting of powerful computers on the one hand and large numbers of cheap disposable sensor nodes (e.g. RFID tags) on the other hand. The range of processing power, storage

capacity, communication interfaces and functionality will be very wide. Moreover various wired and increasingly wireless link technologies with very different characteristics will coexist. The way networks are managed nowadays by specialized system managers is not scalable to these future networked embedded systems, because of the sheer numbers of components, the system dynamics, the heterogeneity of devices and subsystems. Systems need to be self-configurable and self-optimizable.

Self-configuration and reconfiguration implies that components are able to bootstrap without operator intervention, detect their environment (neighboring components) and context, are able to connect to other components and organize themselves in a network. This process may, depending on the complexity and the extent of the physical distribution of the system, have to repeat itself at a higher level and form overlay networks between components and subnetworks. The system should be conscious of its purpose, i.e., the applications it has to support and form and configure itself accordingly.

Self-optimization is a requirement, since the resources in future wireless ad-hoc networks are likely to be limited (e.g., energy supplies, capacity of radio channels), and, operating conditions and system mission may change in unpredictable ways. Ad-hoc networks should be able to capture and act upon changes in their environment, e.g., car networks may want to sense the presence of other networks belonging to other cars and, depending on the speed of the car decide to link up and start up cooperative applications to enhance safety. This behavior is called context aware. Context awareness is a very active research theme; however context in relation to driving the formation and self-organization of embedded networks is only starting to be addressed.

Finally, networks should be reliable. People will start to rely on them heavily, without noticing their presence. They will form the backbone of automated systems, e.g., for vehicle safety and protection against industrial accidents. They will also have to be trustworthy, i.e., they will have to satisfy stringent requirements regarding dependability, security and, for person oriented applications, privacy.
This implies the aforementioned self-healing and reconfiguration, but also self-protection against threats, because of the limits on the response time to threats.

Application areas
Personal networks, Emergency networks, Sensor networks, Home networks, Access networks, Ad hoc networks, Vehicle networks, Health monitoring, Economic impact can be expected on the ICT sector, transport sector, health sector, public sector and safety sector.

Towards Intelligent Environments

Increasingly products and environments will be equiped with intellligence that can observe, anticipate and respond to the user. The challenge is to make these systems easy to program and easy to interact with.

The SRA Ambient Intelligence is investigating a new paradigm for bringing the flexibility of information technology to bear in every aspect of daily life. It foresees that people will be surrounded by deeply embedded and flexibly networked systems that provide easily accessible yet unobtrusive support for an open-ended range of activities, to enrich daily life and to increase productivity at work.

Illustration: Freeband

These systems will be quite different from current computer systems, as they will be based on an unbounded set of hardware artefacts and software entities, embedded in everyday objects or realized as new types of device. Cooperation between individual entities is a necessity, because isolated entities may not be able to perform their tasks with sufficient quality or efficiency, or not reach the required distributed control objectives. Objects should be seen as encapsulating entities, mixing hardware and software in any proportion and at any level of complexity: an object may thus be as simple as a sensor, or as complex as a portable device, or even an entire car or building, depending on the context.

However, such systems will only be viable if they support many diverse applications concurrently, and if they remain open towards unforeseen uses. Applications will execute on behalf of different stakeholders with potentially competing and conflicting interests. Their execution will involve many software entities across distributed and embedded devices. Users, applications and devices will compete for resources such as processing time, memory, communication bandwidth, and sensors/actuators, and they will need to be able to negotiate access. The multitude of devices and computational processes all require energy for their operation, but energy will be a particularly scarce resource that needs to be carefully managed not only at device-level but across entire ambient systems.

The supporting architectures should be open, distributed and scalable, naturally integrating heterogeneous devices ranging from tiny actuators to large computers. It will combine architectures, systems support, networking, data processing and tools to support timely reactivity and pro-activeness, reconfigurability, real-time adaptation, dependability, and context sensitivity.

Aims and mission
The overall aim is to develop a new generation of architectures for pervasive computing environments that supports at their core the evolutionary features in the world we inhabit today. The architecture that we envision promotes co-evolution of pervasive computing environments and their users, and of embedded digital infrastructures and their physical settings.

SRA Ambient Intelligence

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Industrial partners
There are numerous industries highly interested in this area, including larger companies such as Philips, IBM, NXP, Thales, TNO, Océ, LogicaCMG, as well as small and medium–sized enterprises such as Nedap, Chess, Ambient Systems, Roessingh.

Our approach to enable ambient intelligent systems depends on highly distributed, reliable, and secure information systems that can evolve and adapt to radical changes in their environment, delivering information services that adapt to the people and the services that use them. These distributed systems must easily and naturally integrate devices, ranging from tiny sensors and actuators to hand-held information appliances. Such devices will be connected by short-range wireless networks, as well as by high-bandwidth local backbones. Data and services must be secure, reliable, and high-performance, even if part of the system is down, disconnected, under repair, or under attack. The system must configure, install, diagnose, maintain, and improve itself – this applies especially to the vast numbers of sensors that will be cheap, widely dispersed, and even disposable.

In order to make this possible we need to build an underlying architecture for pervasive environments that "opens up" to allow a diverse set of stakeholders to control, manage and influence the process of change in order to create sustainable future environments. We approach our vision with a programme of research in which fundamental innovation activities that address the need for new principles, models, methods, and tools are interwoven with experience projects that study contexts of use in different settings.

Research topics
To scope our SRA we will concentrate on a set of core challenges and research topics that we consider most important for the realization of this vision. The core challenges related to the state of the art that we identify are:

- *Embedded Networking*. Embedded devices vary largely in their wireless communication requirements and therefore interoperability across different technologies needs to be investigated. In addition there is still a need for new protocols that meet the requirements of very low-power and low-resource embedded devices.
- *Competition*. Experimental ubiquitous computing environments typically support a very small number of 'assumed to be friendly' applications but future ambient systems will only be viable if they support many diverse applications executing on behalf of different users with potentially competing and conflicting interests. Users, applications and devices will compete for scarce resources in a dynamic heterogeneous environment, posing resource management challenges at a new scale of complexity.
- *Adaptability*. The sheer number of entities that make up ambient intelligent systems implies that access to resources will be extremely competitive. Hence, these systems will have to embody adaptability on an entirely new scale. For example, communication will need to become adaptive to sustain high densities of devices, and computations may need to split and migrate to adapt to available energy and communication.
- *Integrated development*. Ubiquitous computing systems and applications are developed ad hoc as we lack the abstractions, tools, methods and development frameworks required to easily integrate infrastructure components.
- *Dependability* (i.e. availability, reliability, integrity and maintainability) as embedded systems are business or safety critical in almost every human endeavour;
- *Low-power microelectronics*. As the devices will be integrated in the environment, small size and energy efficiency will be essential. This requires the development of technologies in the areas of low-power RF, mixed-signal microelectronics, energy scavenging, System on chip, and MEMS.

Cross-disciplinary techniques, methodologies and paradigms, for both functional and non-functional requirements, will be vital for the design, test, simulation, abstraction, compilation, programming and run-time support of these architectures. This includes the analysis and optimization of networking protocols and distributed data processing, the study of energy-efficient architectures and circuits, and the supporting design and test environments.

We approach our vision with a programme of research in which fundamental innovation activities that address the need for new principles, models, methods, and tools are interwoven with experience projects that study contexts of use in different settings. The particular scientific methods to be used will range from mathematical modelling (e.g. for resource optimization problems), simulation (e.g. of network protocols), hardware/software prototyping (e.g. of smart devices), and system

measurements to scenario design, contextual analysis, and system evaluation in situ.

Application areas
The exploitation is expected to have immediate utility in an abundance of industrial, medical, civil and safety applications. Among the application domain are for instance

- Health systems: for better individual health monitoring and tools for health professionals
- Safety and security: monitoring safety-critical systems and providing digital safeguards
- Transport: improving safety, efficiency and comfort
- E-inclusion: supporting people with special needs, and including all sectors of society
- E-work: new methods of work, team work, and mobile workers
- Socialisation: nurturing and strengthening social relationships
- Sanctuary: improve people's environments to afford more relaxation and personal sanctuary

International context
The SRA is fundamentally relevant to EU framework from a scientific and technical perspective, as well as from a societal and strategic viewpoint. It adheres completely to the strategic objectives of the EU IST. It is also in line with the vision of several Bsik initiatives, such as Smart Surroundings, Freeband, and MultimediaN.

Safe and Secure Internet and beyond

The overarching research question is: how to establish and maintain trust in the current and future Internets?

"The Internet is broken" is the title of a thought provoking interview with David Clark[1], one of the architects of the Internet. The essence of this and many other articles is that the Internet lacks intrinsic security and privacy mechanisms. (Spear) phishing attacks, spyware, spam, hackers, and viruses are everywhere; malevolent adults pose as children in chat rooms; newspapers are full of stories about Internet thieves stealing millions of credit card numbers; identity theft is the fastest-growing crime, and far more. The end-users and their PCs are becoming increasingly vulnerable. Of course there are security protocols, of course there are privacy measures, and of course there are islands of trust, but the problem is getting worse and worse basically because the Internet by design puts the responsibility for trust and security on the end-user. By *trust* we mean the cause and/or effect of good behaviour.

Difficult though these problems may be, it is really only the beginning: the current "Internet of people and their PCs" is now being extended to an "Internet of Things", where an astronomical number of mostly tiny and mobile devices will interact.

Aim and objectives
Our vision is to create Trusted Environments on the current and future Internets to enable new and better services. A Trusted Environment is a controlled part of the Internet, which is governed by specific rules. Admission to a Trusted Environment is regulated, and members can be held accountable for their actions and transactions while their privacy is protected at the same time. Our approach to create Trusted Environments on the Internet consists of developing the following four pillars:

1. *Privacy enhanced Identity Management* that offers users a choice in how they identify themselves and what information they release to whom.
2. *Trust Management* that allows users to build and gain trust even without a powerful third party and in such a way that users can still be held accountable.
3. *Community Management* that protects users who abide by community rules of their own making and which makes it easy to expel users who misbehave.
4. *System Management* supporting fixed, nomadic, and mobile access that relieves users from the headaches of today's security management of all their devices, both small and large.

We will integrate these pillars into a framework, resulting in the end-user interacting more conveniently with the Internet, feeling more confident that identity and data are protected, and finding it more satisfying and cost-effective to use the Internet. The framework allows service providers to gain more confidence in their customers and citizens because of the accountability measures and the secure transaction mechanisms it provides, both of which reduce (financial) risks. Realising our vision is not only a technology issue; we propose an integrated approach bringing together essential disciplines, including IT and security specialists, social scientists, economists, and lawyers.

State of the art
At present, every internet user, individuals, businesses and governments alike, are more or less experimentally discovering how to cope with trust in the online world. In the online world there is no real digital equivalent to the passport or

[1] D. Talbot. The Internet is broken. MIT Technology review, Dec 2005.

SRA Security

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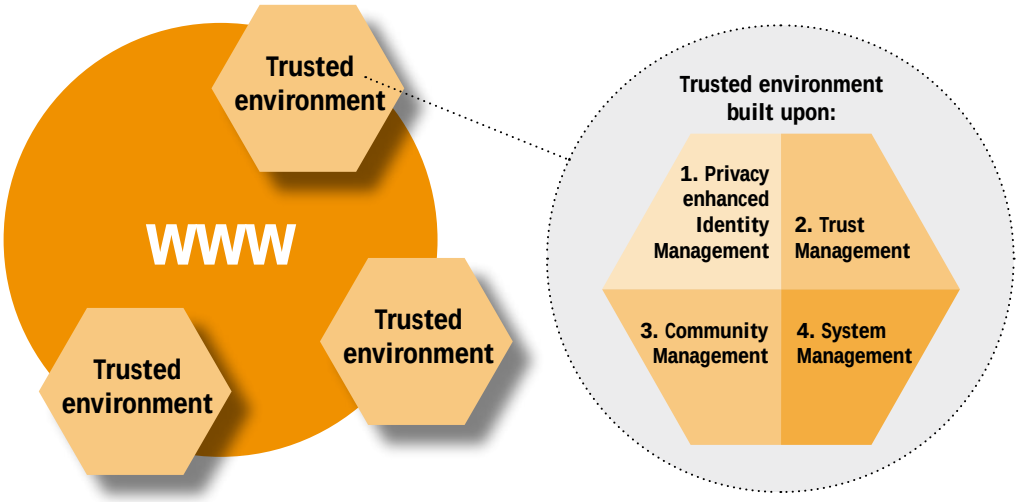
TNT Post Den Haag.



identity card as the standard method of establishing someone's identity. Partly to compensate for this lack of digital credentials, organisations collect a large amount of personal data to be sure that they can address their customers and citizens when needed. Name and address, but also multiple phone numbers, email addresses and credit card data are therefore required for many, even mundane, transactions. This introduces a number of related problems, including:

1. Organisations collect and manage data that is valuable, and hence attract criminals. ID theft, often involving the appropriation of credit card data or identification numbers such as social (fiscal) numbers, is the fastest growing crime, particularly in the USA, as evidenced by a constant stream of newspaper articles. Also in Europe ID theft is a major problem: in 2005 in the UK the cost of ID theft was estimated to be £1.7 billion.

2. Users have to fill in the same data at many places. Identity management at present is organisation centred; each organisation has its own ID data silo. The user can not take her digital identity from one organisation to another in a secure and convenient way.

3. The data collected by service providers is inaccurate. The use of fake information by users is common to avoid the risk of attracting SPAM, or simply because the user does not want the service provider to have the data. This leads to severely polluted data bases.

4. The data is unverified. The old internet cartoon "on the internet no one knows you're a dog" captures this nicely. Online identity claims are difficult to verify. Therefore, the trust provided by the personal data provided is superficial and can be manipulated.

5. Personal data is being misused and or abused. Email addresses provided in return for access to services are sometimes used for spamming. Phishing, Pharming, viruses, and spyware are devised to collect personal data that can be used for ID fraud.

The importance of identity-, trust-, community-, and system-management for increasing trust, as well as for other reasons is acknowledged by many. Many organisations try to address the issues on their own, for example focusing on their own identity management silos. This only solves part of the problems mentioned above and as more incompatible technologies emerge, this may eventually stall the growth of the economy and block social development. The growth of the Internet will therefore not be sustainable. A classic example of unsustainable growth accompanying neglect of user concerns is the stalled deployment of RFID tags.

Economic relevance

The market orientation is "think big, start small". The four applications will bring better health and well being services, interoperable content delivery services, new grass root initiatives and enhanced e-government services. The Netherlands, with its dense Internet coverage, its cultural diversity, and its entrepreneurial population is in an excellent position to take the lead in securing the Internet. Our technology will spark new markets for universal, open security and identity management

devices. The technology partners will develop the framework. Application partners will introduce advanced services. Both the technology partners and the application partners are in a strong position to introduce the results into new and existing open standards, to introduce the technology into the Dutch market first, and then to expand into Europe and beyond, thus giving the Dutch industry a boost in the growing security market.

Trusted environments will provide new ways for people to engage in social interaction, where people will feel that they are in control over their own "digital" lives, just like in real life. The test bed will enable a variety of large scale social, economic, legal and ethnographic studies into online security and trust issues in the online world. The infrastructure will empower grassroots communities to develop secure and trustworthy online environments, allowing vulnerable and insecure users to participate in the digital era.

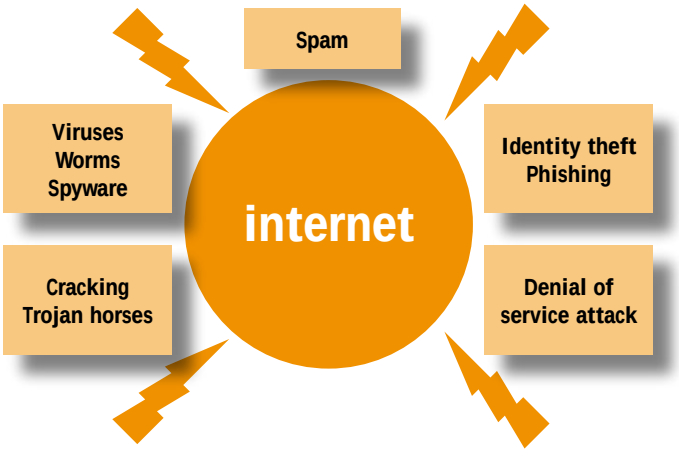
Application areas
The framework will be implemented and tested by significant numbers of individuals and organisations in key application areas spanning both the private sector and public sector, and where trust is a key factor of success. The application areas include:

- Ambient assisted living – improving the quality of life by secure remote monitoring and treatment.
- More content than ever – ensuring interoperability of digital content rendering with redistribution policies that satisfy both producers *and* consumers.
- Virtual communities – empowering netizens, supporting grassroots initiatives and open content licences with self regulatory policies and instruments.
- Citizen central – harmonising identity management in the public and private sectors based on chains of trust and user control.

Dissemination of results
The intended results include (1) a small device (the Nymbus), which manages a user's identity (including the coupling of the physical and digital identity via biometrics) and which shields her from Internet threats (privacy invasion, identity theft etc.) via peer-2-peer communication with other Nymbi. (2) A collection of innovative secure services in the application areas described above. (3) A large, nation-wide test bed will serve as a unique laboratory for the validation of the results. The test bed with the Nymbi and the services will be the start of a Safe and Secure Internet.

The intended results will include methods, techniques, tools and *open* standards to realise the pillars and the applications; Deployment and exploitation plans to take the test bed and Nymbus prototypes into the market; Proposals for legal instruments for security, privacy and trust to the National and European legislators; New business models; New ways of trading and exchange that support grass root initiatives; Awareness raising, educational and social involvement programmes; Strengthening the Dutch security research community represented by www.nvso.nl.

International context
The consortium forms a multidisciplinary collaboration of leading industries and internationally renowned technical and non-technical academics who have been involved for many years in



research on online security and trust. The partners are world-wide suppliers of security solutions and key contributors to many relevant European and International projects and developments, such as the EU PRIME and FIDIS projects, the US led Liberty alliance, the Universal Postal Union, and international DRM and security standards.

The industrial partners of the consortium form a strong combination of multi-nationals, government and SMEs, while the academic partners are the leading security specialists from all the relevant disciplines. The consortium is unique in that it is focused, yet broader in scope than any other multidisciplinary identity management or internet security consortium world wide. We believe that this breadth is essential to deliver highly convenient and cost-effective solutions which users, businesses and government can trust, build upon and tailor to their individual needs.

Educational potential

Industry and government currently have significant difficulties hiring academics with a thorough background in ICT security. To address these needs, in September 2006, RU, TU/e and UT started the first Dutch masters program in ICT security http://www.kerckhoffs-institute.org/. We expect a few dozen students to graduate from this program each year. However, the demand for qualified Master students is greater, and there is also a significant demand for academics with a doctorate in ICT security. The expectation is that the PhDs from the present SRA will be able to satisfy a significant fraction of the marked demands.

Natural and Intuitive Interaction and Information Access

So the main challenge is to improve the ease of use of new technologies in computer-mediated environments in order to turn smart surroundings into habitable environments.

Our home, office, mobile and public environments will increasingly be equipped with smart hardware and software devices, including mobile robots, virtual humans, smart furniture and various sorts of digital assistants that provide real-time support of our activities (work, entertainment, leisure, family, social events, etc.). To maximize their benefit for the user, such environments need to allow easy and transparent interactions with the user and between the users, and to be capable of interpreting, predicting and reacting to user's current and future activities and interests, respectively.

Natural and intuitive interaction requires research into verbal and nonverbal communication issues, modality allocation and integration, and user profiles. *Information access* addresses the challenges of problem-, context- and user-centric interpretation, filtering, delivery and exchange of information generated in or communicated through the environment. Here, research is required on multimodal data storage and processing (e.g. restoration, enhancement and compression), on content-based multimodal data analysis and indexing, as well as on quality of service (QoS) in relation to content exchange and delivery.

Syntactic, semantic and pragmatic analysis of multimodal input and multimedia data can take place in a static (off-line) or dynamic (online) context. In the former case the emphasis is on providing intelligent access (retrieval) to stored multimedia, where 'intelligent' stands mainly for context awareness and personalization. In the latter case we have multimodal interaction with reactive and pro-active smart environments and devices. Here, the multimedia content analysis as well as mixed reality and virtual humans are among the research topics addressed.

Aim and Mission

Our mission is twofold:

- to support multimodal and unobtrusive interactions with and within smart (desktop, virtual human, robot, furniture, wearable, immersive) environments, and
- to enable natural and intuitive access to multimedia information presented or generated in or delivered to the user through anticipatory desktop, ambient, virtual and mixed reality environments.

Research on interaction focuses on the human portion of the human-computer interaction context. We look beyond the traditional keyboard and mouse to include natural, human-like interactive functions including understanding and emulating behavioural, affective and social signalling. The design of these functions require explorations of what is communicated (linguistic message, non-linguistic conversational signal, emotion, person identification), how the information is communicated (the person's facial expression, head movement, tone of voice, hand and body gesture), in which context the information is passed on (where the user is, what his current task is, how he/she feels), and which (re)action should be taken to satisfy user needs and requirements.

Regarding the information access, the challenge we aim to meet is to make the best out of the data and information overflow resulting from numerous sensors present in the environment and from the (typically broadband) information channels reaching the user from outside the environment. This translates mainly to the challenge of finding the information that is relevant for the given user in a given situation and delivering it to the user in a way which is as good and transparent as

SRA Multimedia and Interaction

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possible. Here, just like in the case of interaction, it is necessary to take into account the context, the user characteristics (cognitive functioning and emotional features) and user preferences in order to be able to adapt the information filtering functions of the environment such that intuitive and natural access to multimedia information becomes possible.

Applications can be found in the areas of ambient intelligence, and (collaborative) virtual environments. It is the ultimate goal to increase the "experience" and "presence" within these (virtual) environments and to develop natural interaction techniques (gestures, facial expressions) and more powerful methods to browse distributed multimedia databases ("picture search"), data mining and visual exploration of information spaces, and to create and animate 3D virtual worlds.

This mission translates into several research challenges in the areas of **Multimedia**, **Natural Interaction**, and **Virtual Reality and Visualization**.

Multimedia
This research track covers the steps that are to be performed on the data within an ambient intelligence environment to enable robust, context-aware sensing, data and information processing, interpretation and access between the environment components and users.

- **Context-aware sensing, multimedia data processing and interpretation:** One of the main challenges when designing an ambient intelligence environment is to capture the context and the intention of the users or agents (human or otherwise) that play a role in that environment. For instance, smart cameras equipped with algorithms for multimedia content analysis (MCA) can be employed for surveillance and people monitoring tasks. Such cameras can be programmed to detect specific events or "simply" to estimate the suspiciousness of the situation based on measured audiovisual signals, and react to such events and situations by alarming the users and offering support in the decision making process and for the actions decided upon. Applications stretch from public safety, via people monitoring in elderly homes, to the systems capable of observing and learning the user behaviour for the purpose of anticipating his future actions and adapting the smart environment accordingly.

- **Personalized content access:** A smart environment should have a functionality of enabling the user to easily access and manage the information reaching the environment from the outside world. Examples of devices where such functionality is needed are intelligent personal video recorders capable of filtering the incoming TV broadcast material according to the genres and topics that are of interest for the user, as well as handheld devices (e.g. mobile phones, PDAs) capable of summarizing and presenting to the user the news of the day or the highlights of a soccer match. Rich content of multimedia signals and documents, built through synergies of the information contained in different modalities, calls for new and innovative theories and algorithms of multimedia content indexing. Robust and reliable indexing tools will optimally employ audio, image and video processing, language & speech technology and advanced pattern recognition techniques to model, process, mine, organize, classify and index multimedia data at the semantic level. In particular, to exploit synergies in multimedia data, reliable learning, data fusion, classification and classifier

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Academic partners international
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Industrial cooperation
Philips Research, Microsoft Research Asia, Thales, Philips Medical Systems

combining techniques are required that can simultaneously handle data from different modalities. Next to content indexing, methods and techniques for content personalization are needed to adapt the representation of multimedia content to the needs of a user. Finally, the distributed intelligent media-rich applications as foreseen in our ambient intelligence scenarios also require ambient databases and data management for an ever varying collection of (multimedia) sensor and data sources that is in reach.

Natural Interaction

This research track addresses the development of natural and intuitive interfaces for interaction processes within ambient intelligence environments and virtual worlds. New interfacing technology should enable a large diversity of devices (mobile robots, wearables, furniture, handheld devices) to interact in a natural way with each other, with human users, and with sensor-equipped smart environments (smart homes, smart offices, smart public spaces) themselves. The paradigm shift towards natural human-machine interfaces requires exploiting the synergy of interaction through speech, body motion, facial and gesture communication. This can only be accomplished by a technology that will enable seamless, integrative and context-sensitive interpretation of information streams from different modalities. At the back-end side of the interface we need intelligent agents to communicate and find and perform services for the user.

- **Natural multimodal human-machine interfaces.** The research question here is how to sense, fuse and usefully represent the users' verbal and non-verbal interactive cues (speech, hand and body gestures, facial expressions and gaze, physiological signals like clamminess) so that the obtained information can be used to operate (interact with) a computer program or a robot in a natural and intuitive way. An example of the latter is to use the utterance "Put armor" and a finger pointing to a computer-game character to replace a sequence of less efficient and less effective mouse clicks and menu selections. Proactive human-machine interfaces make use of context information such as users' profiles (age, preferences, disabilities, etc.), users' tasks (and their hierarchy), and contexts (date, time, medication), in order to induce responsive systems, intelligent applications and interfaces that are intuitive, assistive and conversational in style.

- **Designing intelligent user interfaces**. Within smart environments, products should not only perform their primary functions but should also be able to communicate with the user and other appliances in an intelligent way. Evaluation of adaptive and intelligent interfaces is a difficult issue as standard usability engineering techniques are not applicable. For such user interfaces, the evaluation should take place in a realistic rich and dynamic context of use and focus on a prolonged usage period. Assessing the reciprocal adaptations of user and interface, and addressing the contextual effects requires a new methodology for user experience sampling.

Virtual reality and Visualisation

This research track addresses techniques for modeling and visualizing virtual environments, either for scientific data visualization, or for simulation and gaming. The task here is to support the user with constraint-based modeling techniques to quickly build dynamic environments that provide the user with a complex and 'realistic' environments to make game play an involving activity. Data visualization techniques are developed to filter and compress large data sets from scientific simulations and medical scanning devices to allow visual browsing and 3D interaction with the underlying physical phenomena.

- **Interactive data visualization** supports browsing of large data sets and information spaces (such as biomedical data). Such visualizations can be designed to allow visual data mining and to help the user to grasp the meaning of the data, and so to support interactive data clustering and classification. 3D display devices such as head-mounted mounted displays and VR stereo projection devices allow us to interactively explore large scientific datasets. To make interaction meaningful the latency in tracking and display should be low. This requires data reduction and data abstraction techniques such as feature recognition to display the data in a compact and semantically meaningful way. In medical applications data visualization is used for pre-operative planning and diagnosis, and for guiding minimal-invasive surgery.

- **Modeling virtual worlds** Building virtual worlds for gaming and simulation is difficult and labor intensive. Further we want virtual characters to act and move as realistically as possible. Motoric and cognitive behavior of these characters needs to be modeled, but also the idea of believable characters from the field of intelligent agents is employed. Constraint-based techniques are used to build dynamic and adaptive worlds. Constraints enable modeling in a declarative way: not specifying every geometric element separately but allowing a higher order and semantically rich specification which is then interpreted and solved to create a specific instance that satisfies the specified requirements. These techniques are being developed within CAD/CAM to built parameterized product models and in games and simulations to create adaptive virtual worlds for level-of-detail or different levels of game play.

Next-generation Enterprise Information Systems

We can see a number of changes in market and society, enabled (some say 'powered') by advanced information and communication technology that strongly influence the way 'the world turns'. These changes take place at a speed that cannot be compared to earlier changes in markets and society, i.e., they are more of a revolution than an evolution:

- stronger integration of both commercial and non-profit organizations to obtain economy of scale advantages.
- outsourcing of business processes to service providers (based on electronic market places)
- using information technology to increase efficiency of business processes, such as shifting front-end process completely to customer self-service and automatic retail of digital goods (most prominently music in digital format) without any human interference at the provider side.
- dynamically choosing partners for production processes or projects in complex supply chains (based on electronic market places) and integrating (automated) processes with them, such as temporary arrangements for providing adaptive, context aware end-user services.
- using real-time process information to make real-time operational (and tactical) decisions, such as monitoring physical goods flows (via RFID) for dynamic logistics management.

Broader scope of EIS
Traditionally, enterprise information systems were limited in their support for intra-organizational business processes. At the moment we see a growing importance of interorganizational (a.k.a. cross-organizational) applications of enterprise information systems in particular in e-business contexts. More and more, this includes dynamical aspects in external links, e.g. with respect to offered functionality and/or with respect to collaborating parties. Emergence of electronic markets for business functions facilities this form of dynamism. Service-oriented architecting is generally considered an important trend in this development.

To provide integrated solutions, new approaches must be developed to guide and manage the construction and maintenance of next-generation enterprise information systems (EIS). These next-generation systems are characterized by an overwhelming functional complexity combined with high requirements with respect to interoperability, flexibility, extensibility, adaptiveness and dependability. They will each employ many of the individual new technologies mentioned to cater for the complex requirements of the organizations they 'serve'.

More and more we see that EIS are built of COTS-components (Commercial-off-the-shelf). In the past, these components were often integrated into one package by one vendor, but today we see that best-of-breed combinations of components of different vendors have a better fit to the business needs. To be able to develop, manage and maintain such systems, a clear and detailed architectural model of a system is required that is related to strategic objectives of an organization, or a network of collaborating organizations.

Architectural modeling has replaced classical specification and design, while programming has changed into configuration and orchestration. Components are replaced in a running system, so redevelopment is a continuous improvement process. Systems management is involved in sourcing questions: make, buy or rent components that deliver required services, as envisioned in business strategies.

SRA Enterprise Information Systems

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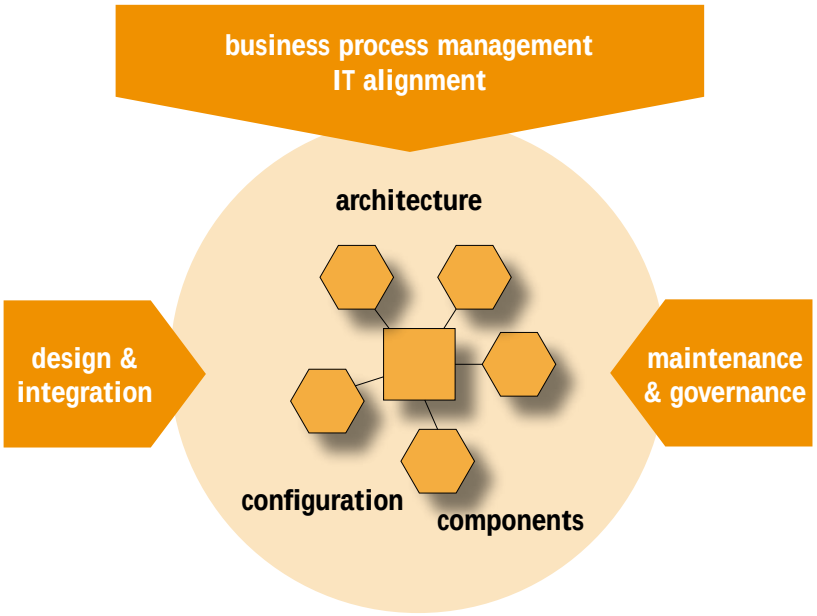
The research in EIS is related to other activities within NIRICT. Software engineering is not an independent topic, but the EIS topic covers a large part of it. There is a strong relationship with the NIRICT laboratories, in particular with the LaQuSo lab, which is specialized in methods and tools for verification of software systems and in particular process models and architectures. With the CTIT program there are several research programs that are complementary to the topics listed here.



As a consequence of the architecture development, the market place has changed dramatically: classical software houses became system integrators, programmers are replaced more and more by consultants that help their clients in selecting, configuring and integrating components. The vendor market is growing: software factories that build generic components for a specific functional area (horizontal market) or for a particular kind of business (vertical market). Both the integrators and the software factories have become much more professional during the last decade.

Research questions

Many research in computer science is demand-driven, i.e. inspired by problems that occur in the development or exploitation of software systems in practice. This is in particular the case in the EIS domain. We classify the research questions related to EIS according to the life cycle of an EIS.

- **Business-IT alignment:** How do we specify the functionality needed and how do we quantify the gap between the offered and required functionality? How do we verify if an information system satisfies conformance requirements from the business?
- **Architecture:** How do we describe an architecture of a system and what kinds of verification methods are applicable for architectures? How do we take into account that an architecture can be specified from multiple viewpoints?
- **Componentization:** How do we determine what useful components are and what the right level of parameterization is?
- **Sourcing:** How do we realize the components needed in the architecture? How can we share services? There are several sourcing approaches: build-time (software construction) and runtime (dynamic service selection).
- **Configuration:** What languages do we need for expressing parameters of components, what are the right methods for parameterization and what verification for parameterization is possible and useful?
- **Integration:** What is the right functionality of integration components, what languages do we need for integration, what are the best methods for integration are?
- **Realization:** What (combinations of) types of ICT are to be used for the realization of an EIS (embodiment of the architecture)? Service-oriented computing is an example of a recent and popular trend, typically using web services to achieve loosely-coupled system architectures.

Research

This section provides a short description of current research and possible new research directions.

- **Business process management**
  The main function of EIS is the support of business processes. Therefore the analysis, design and execution of business processes is a main topic of the EIS domain. The topic is called Business Process Management (BPM) or Business Process Integration (BPI). Note that the process models play a double role: at the business level in the enterprises as well as at

the system level in the support by the EIS. Research focuses on development of models, architectures and automated support for *dynamic interorganizational business processes* (DIBP). During process enactment, collaborator organizations are found by searching business process market places and the sub processes are integrated with the running processes.
Other topics of research are *business process mining* to discover process, control, data, organizational, and social structures from logged data; *configurable process models* as a more flexible method for reference modeling; *analysis of process models* for verification, validation and performance analysis (e.g., via simulation) using formal verification methods (e.g. Petri nets); *adaptive process-aware information systems* to enable dynamic changes of different process aspects and at different process levels. The goal is to maintain a close "fit" between real-word processes and the workflows as supported by IS, the current generation of which is known as Process-Aware Information Systems (PAIS); *enterprise ontology based business process management* as a fully implementation independent conceptual model of (the organization of) the enterprise that is comprehensive, coherent, consistent, and concise.

- **Architecture and development**
  The complexity of large and often inter-organizational information systems require a clear architecture, not only for the development of an EIS but in particular for management and maintenance of these systems. Architecture should be based on models: model-driven architecture (MDA). One of the main development problems is the integration of heterogeneous system components. A successful approach to architecture has it origin in web services: Service Oriented Architecture (SOA), where components are identified with the service they deliver. One of the main problems is the integration of heterogeneous system components. Typical research issues within this theme involve:
  EIS architecture (re)design aims at developing knowledge on architecture principles, but also on the role of architecture in the software engineering process and in an organization. More and more, EIS are built from ready-made components that are bought or consumed as a service. Therefore, architecture design and implementation have to be integrated with sourcing processes. This requires deep technical insight in specification and qualification of architecture component.
  Service-oriented integration aims at reuse and integration of existing system services, rather than building new systems from scratch. New services can be composed by reusing existing ones provided by various service providers. Today powerful integration tools (e.g. different kinds of message-oriented middleware) are available to overcome technical and syntactical heterogeneity. Yet, semantic heterogeneity remains as a major barrier to seamless integration of autonomously developed software components.
  Enterprise architecture based development aims at developing a prescriptive notion of architecture which is complementary to the descriptive notion (blueprint, fundamental organization, etc.). There is a great need for developing formal, probably deontic logic based, specification languages for design, in order to be able to verify the consistency and coherence of a set of principles. Also desired is a compositional framework for architecture that represents the views and options of the multiple stakeholders. The framework should support what-if analysis to select a composition that fits the need of various stakeholders

- **Maintenance and governance**
  EIS have a long life cycle: 10 to 20 years is normal. The contribution of the development cost is in most cases less than 50% of the total cost of ownership. EIS will be modified during their life cycle so there will always be legacy parts. Reengineering will always play an important role in maintenance of EIS. The management of the evolution of EIS has become a serious task in which the alignment of the EIS to the business needs is an important aspect. research issues within this theme involve:
  EIS maintenance and reengineering looks at methods to replace or modify parts of a system because it does not behave properly anymore, due to new user requirements or due to changes in the underlying platforms. The discovery of dynamical structure of software systems is one of the challenges. Different techniques can be used, among which process mining on executions of the software system is a new approach. Generation of parts of an EIS based on the (MDA) models obtained by reverse engineering of existing information systems is another new direction.
  EIS governance addresses compliance of systems with legislation and security requirements.

IT management processes require that a quantitative cost-benefit analysis is present for every EIS development or change project; methods for this are in their infancy. A future trend is to focus on performance ('doing the right things') in IT governance. This gives rise to quantitative models for analyzing application portfolios.

Governance of services in multi-actor networks addresses problems in the way dependencies among public agencies and shared service centre can be coordinated. Governance mechanisms address often an unbalance in value networks. Current research focuses on variety of governance mechanisms and principles to ensure that organizational networks behave in the right directions. The governance of shared services is still an unexplored domain and there are hardly any generic principles and mechanisms. More research is necessary into the types of governance models and which type of governance result in better performance and how networks can be governed.

4. Applications

Because of the enabling character of ICT, there is both a large variety of potential application domains and a whole range of ICT research disciplines. NIRICT has a strong bond with the "sleutelgebieden" High Tech Systems and Materials, and Creative Industries. Research is also done in other areas that are of societal or economical relevance, such as health, mobility, safety, and logistics.

ICT for Mobility

Mobility is a crucial part of our daily life. We commute, go shopping, visit other countries for work and for holidays. Mobility and transport is also the bloodstream of our economy. Globalisation has created enormous amounts of traffic of goods and services. The growth in transport will most likely continue for the coming decades. The growing demand for mobility, of goods in particular, and the limited growth of the necessary infrastructure put permanent pressure on reachability and throughput of the road system, while the reliability is at stake. Traffic congestion, road unsafety, noise, pollution, and CO_2 emission are also responsible for high societal costs, which for the Netherlands only are estimated to be more than 10 billion euro's a year. So there is great concern about the impact of mobility problems on our economical and social well being.

ICT can make a contribution in solving these problems by providing systems and techniques for traffic management, traffic information, safety guidance, camera control, communication, road pricing and context-aware services. For example, networks of cars in which sensors provide local information on position, speed, etc. of neighbouring cars, can help to optimally control the local behaviour of drivers (e.g. driver assistance). Cars interconnected and connected to the infrastructure via e.g. an ad-hoc network, will allow for optimal route allocation mechanisms for reliable reachability. Both on the national and european level there is great need for such innovative techniques.

NIRICT contributes to this development by its research on new and innovative communication infrastructures such as adhoc wireless networks and sensor networks, and by developing intelligent data processing techniques for control, data fusion and data management. Research groups within NIRICT develop models and simulations to understand the behavior of traffic participants and traffic flows, and to come up with better prediction techniques. To develop useful and realistic techniques there is much emphasis on cost reduction, business models, and the societal and legal context. Practical implementations, experiments and pilots play an important role in making these technologies reliable. This all is done in close cooperation with state agencies, construction companies, road management agencies and traffic controllers, both on the national level as on the european level, such as within the EU eSafety Forum and the EU CALM (Communication Air-interface Long and Medium range) initiative.

ICT for Logistics

Workflow & production systems, transportation & supply networks, and service logistics are the backbone for most transport and production related industries, and increasingly also for service oriented industries such as banking and assurance companies and the health care sector. ICT has always played a central role in the management and decision support of these systems, but so far logistics performance and ICT often have been optimized separately. The increasing size and complexity of logistics systems and the resulting vast growth of the ICT environment for data and control communication require a good coordinated design of both logistics systems and their ICT components. An integrated design leads to lower ICT costs, and a better ICT environment will result in better system performance.

Traditionally logistics systems have been implemented mostly as centrally controlled systems. The advent of new ICT technology has drastically changed this perspective. Real-time exchange of information and the application of decentralized optimization algorithms (e.g. using agent technology) on a real-time basis have given rise to completely new possibilities. Ubiquitous computing and communication in sensor networks provide huge opportunities for applying context

information to the logistic flows in supply chains. In this “Internet of Things” new breakthroughs are possible for adaptive control mechanisms and better performance analysis. For instance, designing the hospital of the future requires on the one hand optimal design of patient flows and departments (based on Operations Research techniques), and on the other hand information integration facilitated by (or even driven by) ICT (e.g. “electronisch patientendossier”).

NIRICT contributes to these new developments with research on new and innovative communication structures and sensor networks, and on powerful (decentralized) calculation methods (agents). In addition to the design of efficient multi-agent solutions, ICT systems need to be aligned to the organizational setting, and take issues such as security, trust, information sharing and gain sharing into account. Breakthroughs can be expected in the field of process mining, that will make the model and reality come closer together, such that both conformance (degree to which the system meets its specifications) and performance (degree to which operational objectives are realized) can be measured objectively. In recent years major advances have been made in the area of Operations Research, but the scaling up to the level of business and societal applications is hampered by NP-hardness (there are hardly any optimal solutions for realistic size design and control problems) and the curse of dimensionality (i.e. a system description is required that cannot be practically implemented in databases). Breakthroughs can soon be expected concerning effective heuristics for the design and control of processes at an industrial scale. Participating research groups are contained in TRAIL (TUD), LOIS (TU/e), and the SRO Industrial Engineering & ICT (UT), and form a mix of computer science, mathematics, and more application oriented research.

ICT for Safety

Safety at public places can only be guaranteed when information about accidents and disasters can quickly be detected, sensed, communicated and acted upon. Interpretation of events is only possible, however, when there is enough knowledge available about the local situation and what kind of behavior of the supporting services would be appropriate. Safety is therefore much dependent on the correct interpretation and insight in the opportunities and possibilities to react quickly.

Emergency services (police, ambulances, etc) can perform better when they have a complete and up-to-date view of the situation and a good insight in possible actions that could be initiated. However, in most cases information is incomplete, communication services are interrupted, command structure is lacking, and therefore often wrong and contra-effective decisions are made. A recent analysis of disasters shows that much improvement is possible here. Experts and authorities have always emphasized the organisational context: if the “line of command” would function better then the span of control would be improved. This “top-down” thinking ignores the enormous possibilities that ICT can offer in de-centralized distributed processing for intelligent sensing, interpretation and decision making.

Illustration: Freeband

ICT can have great impact. Wrong interpretations, incorrect decisions and lacking communications may have disastrous results. Every chain in the information and communication pipeline is crucial: is a camera observing standard behavior or is it defiant? Is there only one gas sensor giving an alarm or also the neighboring sensors? “Fusion of information” is a crucial problem! Not only the fixed structure of the communication architecture is important, but also whether it is flexible and can dynamically adapt to the local needs (a reliable multicast is always better than an insecure general broadcast). Is there a ‘shared awareness’ and can information correctly be gathered and distributed? Emergency services often form a de facto ‘ad hoc’ network that can benefit from recent developments in network technology.

NIRICT provides an enormous reservoir of evolving knowledge on sensing, image analysis, language processing, knowledge processing, distributed intelligence, communication, and service architectures. Research groups within NIRICT work with industry to develop safety services and products. Several NIRICT groups participate in DECIS - the institute on ‘Distributed Decision Making’ that focuses on safety as prime application area. DECIS is a joint effort of the technical universities with Thales and TNO and with participation of the Universities of Amsterdam and Tilburg. Within

the projects (BSIK project ICIS, Freeband, Combined, and EU projects) there is collaboration with the harbor authorities in Rotterdam, several police units in Amsterdam, and agencies that organize big public events. The research strives to test new technologies within simulated events and to evaluate the performance in 'situation rooms'.

The application domain 'safety' will draw from several NIRICT SRA's and has already established collaborations with the research units active in them. In particular, the SRA's that concentrate on Networking (the definition of 'ad hoc networks') and intelligence (the usage of techniques for distributed artificial intelligence, pattern recognition, reasoning on stochastic data and data fusion) are relevant, not to speak about various hardware solutions in the area of sensors, sensor networks, computer architectures and ICT infrastructures. These expert group have already been assembled in major projects (as mentioned above) in which also public services are active.

ICT in Healthcare

One of the major challenges we have to cope with is to deliver healthcare to citizens at high quality and affordable costs. In particular, this challenge has to be considered in the light of prevalent trends in healthcare such as prolonged medical care for the ageing population, increasing expenses for managing chronic diseases, and the demand for personal health systems. This emerging situation necessitates a change in the way healthcare is delivered to patients and healthcare processes are managed. ICT will be key to implement these changes and to enable advanced healthcare services. ICT can further contribute to improve illness prevention, to facilitate active participation of patients, and to enable personalization of care.

The challenge is to facilitate a new paradigm of personalized healthcare within the context of an ageing population. Common medical record systems will enable people to receive medical treatment anywhere without having to contact their local doctor or hospital. Citizens will be enabled and supported to live more healthy lives, minimizing time in hospital, at local doctors or in care homes. Home monitoring will become more widely available for people considered at risk. This requires better monitoring regimes for chronically ill patients, through monitoring of vital signs. As a result, the increasingly elderly population will be able to live more independently in their home environment, overcoming isolation and minimizing their reliance on carers. For health and social care providers, services will be focused around more personalized and preventative health management, rather than treatment, while containing the overall cost of delivery.

In order to meet these goals, highly interdisciplinary research is needed which does not only address technical issues, but deals with organizational, legal and regulatory, ethical and societal aspects as well. In particular the following challenges have to be addressed:

- to provide personalized care solutions which enable the participation of patients in healthcare processes and which also respond to the needs of elderly people;
- to provide cost-effective ways to deliver healthcare to patients, and to manage related information and processes;
- to increase patient safety by optimizing medical interventions and preventing errors.

Some scientific and technology ICT challenges are:

- Data communication, including wireless systems that integrate with sensor networks meeting both the medical standards and the clinical requirements;
- Embedded systems as the basis for smart medical implants, home monitoring systems, and other health-related applications;
- Development of a wide range of micro- and nano components (sensors, interconnects, power sources), bio-materials and data communication systems;
- Development of advanced simulation, visualization and modeling, including Grids, to provide new solutions for medical applications;
- Networking solutions to access, search and manipulate huge distributed datasets, including the integration of clinical, biomedical and genomic information;
- Incorporation of organizational perspectives (health management, social care management, etc) and developments in biomedical engineering (e.g. lifelong implantable systems as replacements for non-functioning nerves and muscles and automatic drug delivery systems for the elderly and those with drug-dependent care regimes) into the development of new ICT technologies, services and applications.

NIRICT research activities address many of the above mentioned challenges, and aim at personalized healthcare solutions, optimized healthcare processes, and advanced service architectures for healthcare:

- *Personalized healthcare solutions*:
  Our goal is to develop technologies and infrastructures for realizing personalized care solutions. We aim at innovative services, which enable health status monitoring for chronically ill patients as well as for persons at risk. The integration of these services in healthcare processes and the interoperability with information systems are also addressed. Provided solutions will be based on ambient intelligence techniques, sensor networks, and wearable/mobile ICT systems. They will empower patients to participate in healthcare processes, and facilitate remote monitoring and care at preferred environments (e.g., homes). Altogether these activities will contribute to better health, well-being and mobility.

- *Optimization and ICT support for healthcare processes*:
  Patient treatment requires the cooperation of various healthcare providers and medical disciplines. Thus optimal process support plays a crucial role in order to reduce treatment costs and patient discomfort. This necessitates a close alignment between the healthcare process, healthcare organizations and information about the patient. Research activities include the provision of models and tools for process optimization, and efficiency of resource planning and utilization. Another focus is on ICT support of treatment processes in both healthcare organizations and healthcare networks. Relevant topics include the modeling and automation of healthcare processes, the flexible implementation of medical guidelines and pathways, the realization of lifetime patient records, the provision of patient information and medical knowledge at the point of care, the evolution of healthcare information systems, and privacy and security issues.

Illustration: Freeband

- *Service architectures and health*:
  Our goal is to develop advanced service-oriented architectures for care. Such architectures could provide efficient solutions to many of the problems we encounter in the health domain: interoperability (i.e., sharing health information and connecting health with non-health applications), access (i.e., technology-transparent use of health services and access to healthcare information), and agility (situation-driven composition of health services).

ICT at home

Personal computing and the internet has invaded our daily life. The world wide web provides a rich resource of information and services, be it on travel, tourism, or other leasure products. Digital media (movies and music on DVD and mp3) are easily distributed and communicated. Gaming is evolving in a major activity for the youth. Web communities provide and share information on all kind of topics and provide a social network that ignores local barriers and national borders. The artistic and media-oriented business related to these web and personal services is a fast growing industry that flourishes in particular in large metropoles where both artistic talent and social active “early adapter” groups provide a fertile social and creative environment. Many old city fights for its piece of the cake.
At the same time we see a decline in traditional social structures. Also the educational system is under severe strain. Basic capabilities for grammar and calculus are declining in favor of new media oriented learning and social “chat”. It is yet unclear whether the new learning environments (with video and weblectures) can provide an alternative to the traditional forms of teaching.

ICT is the great enabler of the digital industry. In the early days of computing, ICT was associated with central processors and big storage devices tucked away in air-conditioned rooms in universities and big companies. Since the nineties personal computing and the internet has entered the office and work spaces, and now the private life and houses. Not speed or fast data processing but better

Illustration: Freeband

user-computer interaction is the central issue in the ICT industry as is illustrated by the revival of Apple Computers. The user is surrounded by hundreds of small intelligent gadgets and processors are everywhere either in his car, his video equipment or in his PDA and/or mobile phone. In the near future the user will be surrounded as well with thousands of virtual services that are not directly visible but are available to help the user with his tasks. However, it is difficult to imagine how the user will find the right service ("lost in agent space") and how he will be able tune all the services to his own wishes and needs. Portals will play an essential role in mediating clients and services. Together with the fast developments and crossovers between telephone, tv and cable, this is an exciting area for ICT research and business development in the years to come.

As stated in European research programmes (e.g., the FP7 programme), an important goal for ICT research is "to bring technology closer to people". This can mean hiding the complexity of the technology, revealing the functionality only when it is assumed to be needed and making technology easy to use, available at all time, affordable and adaptable to the users' contexts and preferences. All of these are means to improve the ways in which people can interact with technology. Closely related is the Ambient Intelligence vision as defined in the statement of the theme of the 2nd European Symposium on Ambient Intelligence (Eindhoven, 2004): "Ambient Intelligence represents a vision of the future where we shall be surrounded by electronic environments, sensitive and responsive to people. Ambient intelligence technologies are expected to combine concepts of ubiquitous computing and intelligent systems putting humans in the centre of technological developments." Also in the new Dutch ICT research agenda, the human has entered the loop. In the research themes, "Data-explosion", "Digital Experiences", and "Intelligent Systems", the challenge to design technology with the human user in mind is recognized. Among the long term challenges for intelligent systems, interactions with users come first: "The great challenge for intelligent systems in the long run, is to achieve smooth cooperation between all these intelligent, adaptive and autonomous systems and the human users. Also the European Union has always had a strong interest in promoting the use of ICT for creativity and personal development. The creative industries have also become an important domain in ICT research in the Netherlands, witness several recent initiatives (NWO, NOAG-ict, GATE). The interest for entertainment, art, (new) media, design and games is another way in which technology has to care about the user experience.

NIRICT aims at developing intuitive multimedia interfaces for personal and social computing related to daily tasks such as learning, shopping, entertainment, teleconferencing, communities, etc.

5. Innovation Agenda

One of the goals of NIRICT is to contribute substantially to innovation. NIRICT research creates knowledge which can be used in the development of new ICT products, applications, and services. Innovation requires that ideas which have a commercial potential move from the laboratories into the marketplace. To strengthen the knowledge transfer within the six Strategic Research Agenda's and the NIRICT Center-of-Excellence CeDICT, the joint NIRICT Research Lab (NRL) has been founded.

Knowledge transfer from universities to industry and society

There are several ways to realize knowledge transfer:

- Graduates and research projects: The Dutch economy is becoming ever more knowledge-based; this demands a more highly-skilled workforce. The most important way in which knowledge is transferred from the 3TU's into the wider world is through the skills and experience gained by the numerous graduates and PhDs. In externally funded research projects, knowledge transfer takes place between the participating universities and the industrial project partners (often larger companies and/or high-tech SME's). In general, these - more traditional - aspects of knowledge transfer are taking place within the SRA's.

- Transfer through programmes and projects. These are broad collaborations of university groups, knowledge institutes, branch organisations and individual companies to perform pre-competitive research.

- Licensing and spin-off companies: Licensing of university intellectual property and consulting have long been the traditional methods by which universities have spread their skills and experience into the wider world beyond. In the past few years, the creation of spin-out (or start-up) companies has become an important additional mechanisms through which the knowledge and expertise developed by universities flows directly to industry. Knowledge transfer performance is not easy to measure but if the rate of ICT spin-outs is any guide, the track record of the 3TU's is impressive. NIRICT will build upon the existing successful spin-off activities of the 3TU's, which will be further professionalized within the 3TU Innovation Lab (o.a. stimulation and development of the required mentality and skills of the researchers, TOP arrangements). Coming up with nice ideas and turning them into clever technologies is not sufficient by itself. A clear understanding of how each new technology addresses a real market need is essential, and for this, new skills and dedicated ICT networks are needed. Besides, in contrary to most other disciplines, the possibilities to take out a patent (which can form the basis for a potential business case) are rather limited in the ICT (software) sector; alternative business strategies are required. Therefore, NRL will play a specific supporting role in the process of setting up ICT-knowledge based spin-off companies (although NRL will make use of the standard facilities and knowledge provided by the 3TU Innovation Lab). The cooperation between NRL and ICT-based Business Accelerators (such as Smart Systems) will speed up the expansion of favorable young ICT-based spin-off companies.

NIRICT Research Lab (NRL)

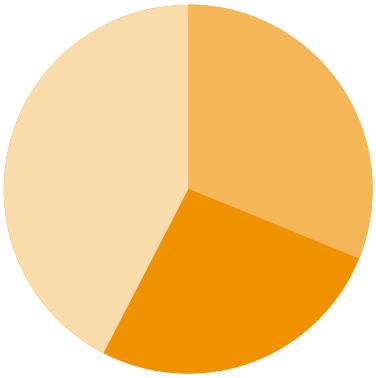
The NRL will initiate and coordinate projects where research expertise is applied to industrial and societal applications, especially for SME's. Because these SME's have a strong basis in their region, NRL will have three locations, although it will be managed as one organization (one board). Each branch will have his own expertise / specialization and a front desk to serve the own region. NRL will be managed by one director and three branch coordinators. Preferably, the NRL activities will be performed by employees of the 3TU's.

LaQuSo (Laboratory for Quality Software)
Scientific leader
Drs. Henk Schimmel (TU/e)

Smart Environment Laboratory
Scientific leader
Prof.dr. Pieter Hartel (UT)

NIRICT Design Labs
Scientific leader
Prof.dr.ir Patrick Dewilde (TUD)

- Website, demo center, brokerage events: NRL will make the NIRICT research results easily accessible for potential (industrial and/or governmental) users via a website specifically addressing particular target groups. Web-based and mobile demonstrators presenting various aspects of NIRICT research (e.g. context-aware ICT services, intrusion detection, mobile eHealth services) will show potential end users the possibilities of research results. At the same time, NRL will play a coordinating role in the organization of meetings such as 3TU customer days and other brokerage events with a focus on the matchmaking between supply (knowledge institutes) and industrial demand.



FTE overview in 2005

Structural Fundings 271,5 fte

Basic Research Funding 220,7 fte

Strategically Research Fundings 346,9 fte

The groups within NIRICT have a substantial involvement in innovation and industry related projects. Next to the structural university funding and basic research funding by the national science foundation, a considerable part of the funding is from strategic research programmes (BSIK, EU, industr, etc.).

LaQuSo (Laboratory for Quality Software)

No matter how carefully software is being developed, at the end only the quality of the product matters, both for the developer and the user. The central question is: does the software system provide the added value which it has promised?
LaQuSo (Laboratory for Quality Software) fully concentrates on measuring, quantifying and predicting the quality of software. This includes the intermediate results that are produced during the development process, as well as the end product, the code of the program. That is why LaQuSo wants to provide its customers a maximal insight in the reliability and predictability of software. More than 50% of software development time is spent on finding errors. LaQuSo helps to decrease this percentage. This is done by developing methods, techniques and tools to detect bugs in artifacts of the software industry. The starting point for all those activities is the problem description defined by the software industry i.e. organizations and departments that professionally develop software.
LaQuSo develops and supports two core competences.

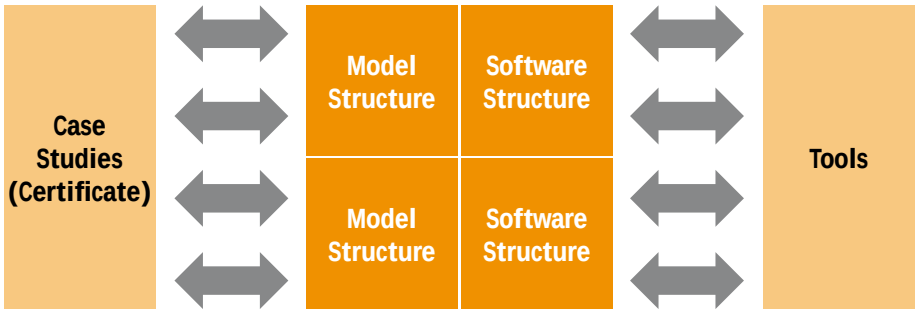
- (Formal) methods, techniques and tools for verification (proving)
- (Empirical)methods, techniques and tools for validation

A Certificate for software

The complexity of software systems is growing. At the same time, the demand for security and dependability increases, this is certainly true for the users' side. Moreover, the legislation puts even higher demands.
This requires an independent evaluation. LaQuSo will achieve this by introducing a quality certificate for software systems or parts of them. The basis for such certificate is a clearly formulated requirements package which can be thoroughly diagnosed by LaQuSo. As soon as LaQuSo does not detect any more errors, there is a foundation for the certificate: "LaQuSo cannot find any more bugs in this system".
LaQuSo is developing itself as "the" expertise and research centre for verification and validation of software systems. Methods and tools come from the scientific world, as well as from industrial practice. LaQuSo will bridge the gap between scientific computer science and software industry. The piles under this bridge are adding value with low thresholds; transforming scientific knowledge

into methods, techniques, and applicable tooling for industry; performing practical case studies; researching with and for the industry and transferring the obtained knowledge and developed methods, techniques and tools to the industry.

Themes and domains
LaQuSo groups its activities into six themes. These are complementary and support each another. The themes optimally fit to both of the goals: increasing the quality of software and bridging science and industry. The themes are presented in the following model:



Research is further focused on 7 domains and services. The domains represent on the one hand the development cycle of software systems i.e. Requirements, Architecture, Software code and Executing systems, and on the other special properties that need special attention, such as Security, User interaction and Performance of software systems.

Tools
The industry has developed a vast amount of tools for verification and validation of software systems. These tools form the instrumental basis for the support of the certification program. Moreover, LaQuSo develops additional tools in-house, and a repository as a mediator between the different views of the system. Due to the formation of the expertise centre these tools will be visible and applicable for industry and the scientific community. This leads to knowledge transfer, practical daily usage and development of new tools.

Methods and techniques for verification and validation form the underlying value for the diagnosis of software systems. The software industry currently does apply a limited number of methodologies. LaQuSo will define and perform new research in cooperation with the industry. Such projects are substantive and financially possible thanks to the good contacts between the industry, LaQuSo, the universities, the ministry of economic affairs and other financial sponsors.

Cooperation
The cooperation between LaQuSo and industry might have several appearances.

- Case Studies:
  In case studies we identify problems, put diagnoses and offer solution directions. Apart from the case studies performed by students within the framework of a training period, we distinguish professional case studies. These lead to a formal diagnosis and possibly to a certification of the examined software system.
- Research:
  Innovation takes place in the research projects which LaQuSo carries out by itself, or with partners. Several research projects concern fundamental research in the field of verification and validation. LaQuSo gives large importance to the research initiated by the industry and to the investigations that are conducted in close cooperation with industry. The industry can outsource research to LaQuSo.
- Expertise centre:
  The available methods, techniques and tools for verification and validation are operational in the LaQuSo Expertise Centre. Interested parties can use the demonstration facilities of LaQuSo.
- Partner of LaQuSo:
  This program contributes to the knowledge transfer by organizing lectures, conferences, publications, demonstrations etc. for industry and science.

Organization
LaQuSo, Laboratory for Quality Software, is a joint activity of 3TU. and Radboud University Nijmegen. All knowledge and capacity in the domain of verification and validation of software systems present at these universities is available via LaQuSo. To guard the focus and bridge between science and industry an Advisory Board with representatives and thought leaders of both the industry and the scientific world advices the direction and the management.

Smart Environment Laboratory (SEL)

Many promising results of research in ubiquitous computing remain in the laboratory because it is difficult to asses the value of experimenting with these technologies in a realistic settings. The costs and benefits of creating such an environment, integrating the technology, and inducing a realistic usage for the ubiquitous services are all highly uncertain factors.

Aim and Vision
In our vision, ubiquitous technologies and services simply should work; for individuals and for groups of people. People should be able to depend on the proper operation of these services, with respect to their availability, reliability, and security. Yet their operation must be intuitively and unobtrusive.
It is our ambition to realise the above vision in The Smart Environment Laboratory (SEL), where we will connect users with core technology such that individuals can appreciate state-of-the-art technology and that their perception will guide the development of technology. Thus facilitating innovative application of technology. The SEL facilitates creative use of technology under development. We will contribute to new applications and business models, contribute to the re-arrangement of the way-of-work for the consequent improvement of productivity, and to contribute to the creation of infrastructure for enhancing the quality of life of people. The use cases in SEL will demand for integration and seamless interworking of technology. Typically, a prototype implementation will suffer from imperfections, resolving these undoubtedly will yield new, expectedly exciting, technology.

Approach
To realise our ambition we are creating an infrastructure in which researchers from a wide range of disciplines work closely together. Some researchers will be working on engineering topics such as communication technology, embedded software and hardware configurations, and security and privacy issues, whereas others will work on topics from the social sciences such as user interfaces, user perception, human monitoring and coaching. A particular asset of our infrastructure is that we effectively close the gap between an individual user and a dedicated technology, which is generally a gap too big to close for individual projects. At each of the three Technical Universities, the SEL has a so-called Smart Network eXPerience lab (SmartXP). Each SmartXP lab is intimately connected to a range of specialised laboratories, through the engineers and social scientists that work in the SmartXP lab. The range of satellite laboratories include laboratories for technology integration and core technology development as well as laboratories for human machine interaction and user interface design targeting specific user groups, of which the emerging home and care labs are distinct examples. A SmartXP lab is a place where technology can be experienced in a realistic setting. It offers people a chance to participate in applications and validation tests. Concurrently, a SmartXP lab offers researchers the opportunity to observe the use of technology and its ability to interoperate with various other technologies. A SmartXP lab is the place where research meets applied technology, mutually strengthening each other.
The Smart Environment lab is self-reinforcing. It is a living lab in which scientists and engineers participate constantly in each-other's applications; they share each-other's technology and they typically will use each-other's applications in their daily life. Moreover, the smart environment lab is a market place for expertise and state-of-the art technology for the next generation of ubiquitous services.

Example
We are working on a system for virtual presence that provides the opportunity to collaborate, participate, and observe at a distance. The same system can be used to distribute applications and to observe its usage in daily life of the SmartXP researchers.

Another example is the health monitoring system. Here researchers experience the fact of being constantly monitored. The monitoring system is integrated with a coaching system that guards the well-being of the researchers. Note that the virtual presence system is a technology under development as well as a tool. We will investigate to what extent the virtual presence will change the way-of-work of our researchers.

Portfolio
The Smart Environment Lab provides easy access to a broad field of expertise; recall hierarchical structure of SmartXP labs and their satellite laboratories. Today, we accommodate a number of projects in the field of health, safety, and well-being related applications, a portfolio which we are actively extending. We believe that an important aspect of future applications will be experience sharing among individuals and amongst groups of people. We hope to welcome soon in our lab representatives from various kinds of user groups as well as representatives of a broad range of technologies. We look forward to work together with industry and research institutes on the next generation of ubiquitous services.

NIRICT Design Labs

The electronic design labs of the three universities have joined their forces in the NIRICT Design Labs, with the aim to open up their facilities for each other, to coordinate the development of new methods and techniques, and to jointly participate in EU projects.

Problem formulation
The design of modern ICT systems are characterized by the need to implement higher functionality and much better performance than was the case with traditional systems and components such as processors, radios, memories or programs. For example, in an 'ambient intelligent surrounding' it is necessary to combine the utilization of special materials, a computer processor, a radio link, several sensors and actuators and an energy supply. Research groups and engineers are more often than not specialized in one specific area, they are specialized in one type of hardware or software and one discipline. If the system asks for the combination of more functions – e.g. sensing and communication, they are often at loss of how the combination can be realized, let alone to dispose of a prototype design for the parts of the system for which they do not have adequate experience. In this way, not only valuable results of research and development get lost, but new systems are not proficiently designed and great opportunities for new systems are lost. We want to remedy this system by providing a repository of information, past designs and tools that should allow each designer to have easy access to all the knowledge and practical experience he/she needs to design systems that combine many more aspects than the own discipline can provide.

Approach
The main carrier for cooperation will be a joint "design platform" that combines design tools (programmes), libraries of components, design methodologies, testing strategies, support for design flows and design cases both in the area of hardware and software design (including embedded software). This platform will be open to the NIRICT partners and students from the three educational programmes, but it will guarantee the "intellectual property" of the individual groups on innovative and new designs. It is also the ambition of the Lab to extent its activities to outside parties, in particular companies. At the moment there are already such cooperations active, also in the EU context where an action in the same direction is taking place. The NIRICT Design Labs will serve as the Dutch participant in these larger programs and may even provide the basic framework for the platform, based on its experience in setting up such a platform for low power integrated system design.

The platform that is envisaged should support heterogeneous design strategies. Many modern designs require the combination of different technologies, e.g. the combination of a sensor with intelligent signal processing capabilties and a 'low power radio'. Large companies in general have enough qualified people to cover these different aspects but young inexperienced researchers and small companies do not always have the expertise and it is difficult to gather the necessary expertise to realize heterogeneous designs. The NIRICT groups have a large resource of strategic knowledge and it is the aim of the Design Labs to make this knowledge available such that it is easier for other partners to make innovative designs. Besides original designs and design tools,

also a great assembly of international contributions and tools will be provided, all organized in a user friendly and accessible way, using modern data repository techniques including the usage of semantic web methods, work flow and version control, search engines and research information. An international board of editors will evaluate and judge the inputs and quality indications of the various components will be given.

The platform will provide a basic design substrate for the other components of the NIRICT program, ranging from hardware to software, with special emphasis on integration and system design. In particular, the NIRICT SRA's aiming at Ambient Intelligent, Broadband Telecommunication systems and Software Engineering should profit from the existence of the platform and contribute to its content.

Current situation
The design platform is being defined and the individual partners now contribute to its contents. This effort will also be made part of the Dutch contribution to the EU design platform ERICA, part of the 'Ecosystem Design' of ENIAC Scientific Community Council (ENIAC is the European Technology Platform voor Nano Elektronica en Embedded Systems). Also companies and other interested users will be invited to contribute to and use the platform. It is our ambition to set up a system that will find wide usage in the overall international community, much as is the case for major libraries of functions such as LAPACK, Some of the same techniques shall be used to create a community of supplier and users, taking into account that also the quality of the supplies must be guaranteed, and that the whole setup must be effective.

6. Concluding Remarks

NIRICT is in its starting phase. Three strong ICT-communities from Delft, Eindhoven, and Twente have expressed their common challenges in the NIRICT Research Plan 2007. Both in terms of volume and of commitment this is a unique step in the Netherlands. The ambition is, together with other Dutch ICT institutes, ICT groups at other universities, and industry, to create a strong ICT position in Europe. In 5 to 10 years time there will be only a few strong ICT regions left. Our ambition is that one of them is in the Netherlands. The High Tech Campus plays a major role in this. To be able to achieve this ambition we have to team up. The founding of NIRICT is a first step in this direction. The cooperation with ESI, TNO ICT, and Telematics Institute is materializing. We hope that other steps will follow.

For the upcoming year(s), NIRICT will further strengthen its international position in Dependable ICT Systems and in the themes of the Strategic Research Agenda. Our three NIRICT Research Labs will be one of the means to achieve this and to become a partner in innovation. Together with others we will contribute to national and international research agendas by forming consortia and working together in projects. It is our ambition that our joint research will be visible and have impact.

The NIRICT Resarch Plan 2007 is a first step in showing our strength and focus. It is meant to be a “live” document is the sense that we will regularly update the document. The latest version will always be available on nirict.3tu.nl.

Appendix 1 Overview NIRICT chairs

TU Delft	
	chair
Witteveen	Algorithmics
Reinders	Bioinformatics
Dewilde	Circuits and Systems
van der Veen	Circuits and Systems
Vassiliadis	Computer Engineering
Jansen	Computer Graphics
Veen	Education and technology
vacancy	Electromagnetism
French	Electronic Instrumentation
Long	Electronics
van den Hoven	Ethics & Technology
van Oosterom	GIS Technology (Geo Information Systems)
de Vreede a.i.	High Frequency Components and Technology
De Ridder	Informational Ergonomics
Bouwman a.i.	Information and Communication Technology
Biemond	Information and Communication Theory
Lagendijk	Information and Communication Theory
Dietz	Information Systems Design
Beenakker	Integrated Circuit Technology
Neerincx	Man-Machine Interaction
Jonker	Man-Machine Interaction
Sarro	Microsystem Technology
Van Mieghem	Networks, Architectures and Services
Verburg a.i.	Organizational Behaviour & Innovation
Sips	Parallel and Distributed Systems
Young	Quantitative Imaging
Van Deursen	Software Engineering
Verbraeck	Systems and Simulation
Ligthart	Telecommunication- and Teleobservation Technology
Niemegeers	Wireless & Mobile Communications
TU/e	
	chair
De Berg	Algorithmics
Van Hee	Architecture of Information Systems
Van der Aalst	Business Proces Management
Van Tilborg	Coding and Cryptography
Woeginger	Combinatorical Optimization
Van den Bosch	Control Systems
De Bra	Databases and Hypermedia
Groote	Design and Analysis of Systems
Otten	Electronic Systems
Tijhuis	Electromagnetics
Koonen	Electro-Optical Communication Systems
Baeten	Formal Methods
Grefen	ICT Architectures
Van Roermund	Mixed-Signal Microelectronics
Smit	Opto-Electronic Devices
Fledderus	Radio Communication
Bergmans	Signal Processing Systems
vacancy	Software Construction
Van Genuchten	Software Engineering

Boxma	Stochastic Operational Research
Lukkien	System Architecture and Networks
Rooda	Systems Engineering
van Wijk	Visualisation
Universiteit Twente	
	chair
Van Sinderen a.i.	Architecture and Services of Network Applications
Van Maarseveen	Centre for Transport Studies
Smit	Computer Architecture & Testing for Embedded Systems
Verweij	Cognitive Psychology and Ergonomics
Van Amerongen	Control Engineering
Apers	Databases
Haverkort	Design and Analysis of Communication Systems
Van Houten	Design, Production & Management
Hurink a.i.	Discrete Mathematics and Algebra
Hartel	Distributed & Embedded Systems
Wouters	Finance & Accounting
Rensink a.i.	Formal Methods and Tools
Nijholt	Human Media Interaction
Wieringa	Information Systems
Hillegersberg	Information Systems & Change Management
Nauta	Integrated Circuit Design
Polderman a.i.	Mathematical Syst. and Control Theory
De Smit a.i.	Operational Methods for Production and Logistics
Achterhuis	Philosophy
Slump	Signals and Systems
Aksit	Software Engineering
Albers	Statistics & Probability
Boucherie	Stochastic Operations Research
Bagchi	Stochastic System and Control Theory
Rip	Studies of Science, Technology and Society
Van Etten	Telecommunication Engineering